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ABSTRACT

This document is an instructional module package prepared in objective form for use by an instructor familiar with groundwater, general well design and construction, basic well maintenance, collection of well performance data, use of data in evaluating well performance and identifying basic well problems, and well system analysis. The module is divided into three submodules; well technology and basic maintenance, evaluation of well performance, and well management. Included are objectives, instructor guides, student handouts and transparency masters. (Author/RH)

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WATER SUPPLY - WELLS

Training Module 2.200.2.77

Prepared for the

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by

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September, 1977

SE 024 037

SUMMARY

Page 1 of 28

Module No:

Module Title:

Water Supply - Wells

Submodule Titles

1. Well Technology and Basic Maintenance
2. Evaluation of Well Performance
3. Well Management

Approx. Time:

30 hours

Objectives:

Upon completion of this module the participant should be able to describe surface and ground water movement, identify well design, construction methods and component parts, set routine and preventative maintenance schedules, and evaluate typical problem situations (both potential and present).

Instructional Aids:

Handout A-1, A-2, A-3, A-4, & B-1, B-2, C-1, C-2
Transparancies #1 - # 30

Instructional Approach:

Lecture
Discussion

References:

1. Johnson Division U.O.P., Ground Water and Wells, Johnson Division U.O.P. 1972.
2. Walton, William G., Groundwater Resource Evaluation, McGraw-Hill, 1970.
3. Steel, Ernst W., Water Supply and Sewerage, McGraw-Hill, 1960.
4. Campbel, M. D. & Lehr, Well Water Technology, McGraw Hill, 1973.
5. Water Supply - Wells - Location, Design & Construction Module.

Class Assignments:

Read handout
Work assigned problems

Module No:	Topic: Summary

Instructor Notes:	Instructor Outline:
Handout A-1 Transparancies #1 - 7	1. Discuss the movement of water through the hydrologic cycle, into the water bearing ground formations, and through these formations.
Handout A-2 Transparancies # 8 - 16	2. Describe the various well designs and functions of the components.
	3. Identify the basic methods of well construction, development, and disinfection
Handout A-3 Transparancies # 17 - 20	4. Discuss water quality and relate to incrustation and corrosion.
	5. Describe basic well maintenance procedures and relate drawdown and yield to problem areas.
Handout B-1 Transparancies # 21	6. Describe ground water movement in mathematicsl terms.
Handout B-2 Transparancies # 22 - 27	7. Plot, interpret and relate well performance plots to problem solving.
Handout C-1 Transparancy # 28	8. List the information included in and discuss the importance of a record file.
Handout C-2 Transparancies # 29 & 30	9. Illustrate well water systems with respect to tower.

The use of technical bulletins from the major manufacturers may be helpful in supplementing information in student handouts.

Module No:	**Module Title:** Water Supply - Wells
	Submodule Title: Well Technology and Basic Maintenance
Approx. Time: 1 hour	**Topic:** Movement of Water

Objectives:

Upon completion of this module, the participant should be able to:

1. Diagram and describe:
    a. Hydrologic cycle
    b. Confined aquifers
    c. Water table aquifers
    d. Movement and sources of water pollution
2. Identify:
    a. Ground formations and affect on water movement
    b. Exploration methods

Instructional Aids:

Handout A-1

Transparancies #1 - #5

Instructional Approach:

Lecture
Discussion

References:

1. Johnson Division U.O.P., Ground Water and Wells, Johnson Division U.O.P. 1972.
2. Walton, William G., Groundwater Resource Evaluation, McGraw-Hill, 1970.
3. Steel, Ernst W., Water Supply and Sewerage, McGraw-Hill, 1960.
4. Campbel, M.D. & Lehr, J. H., Well Water Technology, McGraw-Hill, 1973.

Class Assignments:

Read handout

Module No:	Topic: Movement of Water

Instructor Notes:	Instructor Outline:
Handout A-1 Transparancies # 1 - 5	
1. Emphasize movement of water and storage of water on the earth.	1. Discuss and diagram the hydrologic cycle.
2. Include: a. Slope of surface b. Faults and other geographic formations	2. Discuss factors affecting the movement of water to the aquifer.
3. Emphasize: a. Characteristics of each b. Differences	3. Discuss and diagram the types of aquifers a. Confined b. Unconfined c. Primary - secondary
4. Emphasize: a. Construction b. Structure c. Other wells d. Disposal methods	4. Discuss the movement of pollution into an aquifer.
	5. Briefly describe the various exploration methods including: a. Geophysical logging b. Refraction seismograph c. Surface resistivity

Module No:	**Module Title:** Water Supply - Wells
	Submodule Title: Well Technology and Basic Maintenance
Approx. Time: 1 hour	**Topic:** Movement of Ground Water

Objectives:

Upon completion of this module the participant should be able to identify:

1. The relationship of rate of ground water movement and ground formation.
2. Porosity, permeability, transmissibility and storage coefficient of a given aquifer.

Instructional Aids:

Handout A-1
Transparancies # 6 & # 7

Instructional Approach:

Lecture
Discussion

References:

1. Johnson Division U.O.P., Ground Water and Wells, Johnson Division U.O.P. 1972.
2. Walton, William G., Groundwater Resource Evaluation, McGraw-Hill, 1970.
3. Steel, Ernst W., Water Supply and Sewerage, McGraw-Hill, 1960.
4. Campbel, M.D. & Lehr, J. H., Well Water Technology, McGraw-Hill, 1973.

Class Assignments:

Read handout

Module No:	Topic: Movement of Ground Water

Instructor Notes:	Instructor Outline:
Handout A-1 Transparancies # 6 & # 7	
1. Include discussion of: a. Sedimentary rock 1. Alluvium - (generally good) 2. Sand & Sandstone - (good) 3. Clays & Shales (very poor) 4. Limestone - (variable) b. Igneous rock 1. Extrusive - (variable) 2. Intrusive - (very poor) c. Metamorphic rock 1. Gneiss - (poor) 2. Schist - (poor)	1. Discuss the relationship of the ground formation and movement of water through it.
2. Emphasize definition	2. Discuss an aquifer using the following terms: a. Porosity b. Permeability c. Transmissibility d. Storage coefficient

Module No:

Module Title:

Water Supply - Wells

Submodule Title:

Well Technology and Basic Maintenance

Approx. Time:

1½ hours

Topic:

Well Design

Objectives:

Upon completion of this module, the participant should be able to identify the basic well designs and describe limitations and advantages of each.

Instructional Aids:

Handout A-2
Transparancies # 8 - # 12

Instructional Approach:

Lecture
Discussion

References:

1. Johnson Division U.O.P., Ground Water and Wells, Johnson Division U.O.P. 1972.
2. Walton, William G., Groundwater Resource Evaluation, McGraw-Hill, 1970.
3. Steel, Ernst W., Water Supply and Sewerage, McGraw-Hill, 1960.
4. Campbel, M. D. & Lehr, J. H., Well Water Technology, McGraw-Hill, 1973.

Class Assignments:

Read handout

Module No:	Topic: Well Design

Instructor Notes:	Instructor Outline:
Handout A-2 Transparancies # 8 - # 12	
	1. Discuss well design with respect to selection of an adequate size: 1. Diameter 2. Depth 3. Pumping capacity 4. Sanitary seal
2. Compare: a. Screened with unscreened b. Gravel pack with material pack c. Pitless with design requiring pit	2. Discuss the choice of overall well design with respect to geological formation of aquifer and surrounding area.
	3. Discuss use of quality construction materials.

Module No:

Module Title:
Water Supply - Wells

Submodule Title:
Well Technology and Basic Maintenance

Approx. Time:
1½ hours

Topic:
Components and Function

Objectives:

Upon completion of this module, the participant should be able to identify the components of a well and function of each.

Instructional Aids:

Handout A - 2
Transparancies # 8 - # 12

Instructional Approach:

Lecture
Discussion

References:

1. Johnson Division U.O.P., Ground Water and Wells, Johnson Division U.O.P. 1972.
2. Walton, William G., Groundwater Resource Evaluation, McGraw-Hill, 1970.
3. Steel, Ernst W., Water Supply and Sewerage, McGraw-Hill, 1960.
4. Campbel, M. D. & Lehr, J. H., Well Water Technology, McGraw-Hill, 1973.

Class Assignments:

Read handout

Module No:	Topic: Components and Function

Instructor Notes:	Instructor Outline:
Handout A-2 Transparancies # 8 - # 12	
1. Include mention of different types of each component and special characteristics and precautions of each.	1. Discuss the components of a well and describe the function of each including: a. Well screen b. Casings c. Cement grout d. Pump e. Motor f. Float pipe g. Cover h. Meters and valves

Module No:	Module Title: Water Supply - Wells
	Submodule Title: Well Technology and Basic Maintenance
Approx. Time: 1½ hours	Topic: General Construction Methods

Objectives:

Upon completion of this module, the participant should be able to:

1. Identify the major water well construction methods.
2. Describe the basic differences between the methods.

Instructional Aids:

Handout A-2
Transparancies # 13, # 14

Instructional Approach:

Lecture
Discussion

References:

1. Johnson Division U.O.P., Ground Water and Wells, Johnson Division U.O.P. 1972.
2. Walton, William G., Groundwater Resource Evaluation, McGraw-Hill, 1970.
3. Steel, Ernst W., Water Supply and Sewerage, McGraw-Hill, 1960.
4. Campbel, M. D. & Lehr, J. H., Well Water Technology, McGraw-Hill, 1973.

Class Assignments:

Read handout

Module No:	Topic: General Construction Methods

Instructor Notes:	Instructor Outline:
Handout A-2 Transparency # 13 - # 14	
1. Emphasize the points which differ between methods including: a. Setting casing b. Setting screen	1. Discuss and diagram various well construction methods including: a. Drilled wells 1. Cabel tool 2. Rotary b. Augured wells c. Jetted wells d. Dug wells

Module No:	**Module Title:** Water Supply - Wells
	Submodule Title: Well Technology and Basic Maintenance
Approx. Time: 1 hour	**Topic:** Development and Disinfection

Objectives:

Upon completion of this module, the participant should be able to:

1. Identify reasons for and methods of well development.
2. Describe reason for and methods of well disinfection.

Instructional Aids:

Handout A-2
Transparancies # 15 & # 16

Instructional Approach:

Lecture
Discussion

References:

1. Johnson Division U.O.P., Ground Water and Wells, Johnson Division U.O.P. 1972.
2. Walton, William G., Groundwater Resource Evaluation, McGraw-Hill, 1970.
3. Steel, Ernst W., Water Supply and Sewerage, McGraw-Hill, 1960.
4. Campbel, M. D. & Lehr, J. H., Well Water Technology, McGraw-Hill, 1973.

Class Assignments:

Read handout

Module No:	Topic: Development and Disinfection
Instructor Notes:	Instructor Outline:
Handout A-2 Transparancies # 15 & # 16	1. Discuss well development including: a. Reason for: 1. Corrects clogging 2. Increases porosity and permeability 3. Stabilizes formation b. Methods: 1. Surging 2. Overpumping 3. Backwashing 4. Jetting 2. Discuss chlorination of well to disinfect including: a. Reason for b. Methods of

Module No:	Module Title: Water Supply - Wells
	Submodule Title: Well Technology and Basic Maintenance
Approx. Time: 2½ hours	Topic: Water Quality - Incrustation and Corrosion

Objectives:

Upon completion of this module, the participant should be able to identify:

1. The relationship between water quality, incrustation and corrosion.
2. The treatment used to correct or improve the problem situation.

Instructional Aids:

Handout A-3
Transparancies # 17, # 18

Instructional Approach:

Lecture
Discussion

References:

1. Johnson Divison U.O.P., Ground Water and Wells, Johnson Division U.O.P. 1972.
2. Walton, William G., Groundwater Resource Evaluation, McGraw-Hill, 1970.
3. Steel, Ernst W., Water Supply and Sewerage, McGraw-Hill, 1960.
4. Campbel, M. D. & Lehr, J. H., Well Water Technology, McGraw-Hill, 1973.

Class Assignments:

Read handout

Module No:

Topic:
Water Quality - Incrustation and Corrosion

Instructor Notes:

Handout A-3
Transparancies # 17 & # 18

1. Relate each problem with cause and treatment

Instructor Outline:

1. Discuss water quality as it relates to:
    a. Incrustation
        1. Bacteria
        2. Mineral
    b. Corrosion
2. Discuss:
    a. Acid treatment
    b. Chlorine treatment
    c. Explosive treatment
    d. Jetting

Module No:

Module Title:
Water Supply - Wells

Submodule Title:
Well Technology and Basic Maintenance

Approx. Time:
3 hours

Topic:
Preventative Maintenance

Objectives:

Upon completion of this module the participant should be able to:

1. Describe techniques for measuring drawdown
2. Develop a maintenance schedule for a well and its components.
3. Identify the necessity of preventative maintenance.
4. Identify problem areas which can be predicted and corrected early by preventative maintenance.

Instructional Aids:

Handout A-3
Transparancies #19 & # 20

Instructional Approach:

Lecture
Discussion

References:

1. Johnson Division U.O.P., Ground Water and Wells, Johnson Division U.O.P. 1972
2. Walton, William G., Groundwater Resource Evaluation, McGraw-Hill, 1970.
3. Steel, Ernst W., Water Supply and Sewerage, McGraw-Hill, 1960.
4. Campbel, M. D. & Lehr, J. H., Well Water Technology, McGraw-Hill, 1973.

Class Assignments:

Read handout
Plot graphs along with instructor

Module No: –

Topic: Preventative Maintenance

Instructor Notes:	Instructor Outline:
Handout A-3 Transparancies #19 & 20	
1. Emphasize setting schedule and techniques.	1. Discuss well maintenance including: a. Drawdown b. Pump wear c. Motor, valve and meter checks
2. Include problems on a. Depleting aquifer b. Pump wear c. Incrustation	2. Develop a model maintenance schedule.
	3. Explain and diagram problems which can be predicted with an adequate preventative maintenance schedule.
	4. Have students plot problems, calculate storage coefficients and examine results of problems diagrammed along with instructor on pages provided in Handout A-3.

Module No:	**Module Title:** Water Supply - Wells
	Submodule Title: Evaluation of Well Performance
Approx. Time: 2 hours	**Topic:** Ground Water Movement

Objectives:

Upon completion of this module, the participant should be able to:

1. Describe ground water movement in a given aquifer using the following terms:
    a. Porosity
    b. Permeability
    c. Transmissibility
    d. Storage coefficient
2. Describe aquifer uniformity with respect to sieve analysis.

Instructional Aids:

Handout B-1
Transparancy #21

Instructional Approach:

Lecture
Discussion
Problem Solving

References:

1. Johnson Division U.O.P., Ground Water and Wells, Johnson Division U.O.P. 1972.
2. Walton, William G., Groundwater Resource Evaluation, McGraw-Hill, 1970.
3. Steel, Ernst W., Water Supply and Sewerage, McGraw-Hill, 1970.
4. Campbel, M. D. & Lehr, J. H., Well Water Technology, McGraw-Hill, 1973.

Class Assignments:

Read handout
Work given problem

Module No:	Topic:- Ground Water Movement

Instructor Notes:	Instructor Outline:
Handout B-1 Transparancies #21	
1. Emphasize relationship, formulations and calculations of: a. Porosity b. Permeability c. Transmissibility d. Storage coefficient	1. Discuss ground water movement through the various geological formations.
	2. Give practice problem on ground water movement with respect to expected yield of a given well.
	3. Discuss sieve analysis with respect to well design.

Module No:	**Module Title:** Water Supply - Wells
	Submodule Title: Evaluation of Well Performance
Approx. Time: 4 hours	**Topic:** Determining Well Performance

Objectives:

Upon completion of this module, the participant should be able to:

1. Define drawdown.
2. Plot drawdown from data obtained from pumping tests.
3. Relate well diameter and drawdown to yield.
4. Identify the effect of pumping rate, well spacing, boundaries, pumping time, and well diameter on drawdown and well capacity.
5. Given formulas use time and distance drawdown curves to calculate transmissibility and storage coefficient.
6. Plot and evaluate recovery.

Instructional Aids:

Handout B-2
Transparancies #22, 23, 24, 25, 26

Instructional Approach:

Lecture
Discussion
Problem Solving

References:

1. Johnson Division U.O.P., Ground Water and Wells, Johnson Division U.O.P. 1972.
2. Walton, William G., Groundwater Resource Evaluation, McGraw-Hill, 1970.
3. Steel, Ernst W., Water Supply and Sewerage, McGraw-Hill, 1970.
4. Campbel, M. D. & Lehr, J. H., Well Water Technology, McGraw-Hill, 1973.

Class Assignments:

Read handout
Solve assigned problems

Module No:

Topic:
Determining Well Performance

Instructor Notes:

Handout B-2
Transparancies #22, 23, 24, 25, 26

Instructor Outline:

1. Discuss what drawdown is and demonstrate using pumping test data how to plot a:
   - a. Time-drawdown curve
   - b. Distance-drawdown curve
2. Discuss and illustrate the relationship of:
   - a. Well diameter and yield
   - b. Well diameter and drawdown
   - c. Drawdown and yield
3. Discuss and demonstrate use of drawdown curves to calculate:
   - a. Transmissibility
   - b. Storage coefficient
4. Discuss the effects of the following on the cone of depression, drawdown and well capacity:
   - a. Well diameter
   - b. Pumping rate
   - c. Pumping time and recovery rate
   - d. Well spacing
   - e. Boundaries
5. Give students problems to solve over using the pumping data to:
   - a. Plot and interpret drawdown curves
   - b. Plot recovery rate
   - c. Calculate
     1. Well efficiency
     2. Transmissibility
     3. Storage coefficient

Module No:	**Module Title:** Water Supply - Wells
	Submodule Title: Evaluation of Well Performance
Approx. Time: 2½ hours	**Topic:** Basic Problem Solving

Objectives:

Upon completion of this module the participant should be able to:

1. Distinguish between common well problems from pumping test data.
2. Given a typical situation determine the effect of a new well upon drawdown in a nearby well and identify possible corrective measures.
3. Identify alternatives when boundaries create drawdown complications.

Instructional Aids:

Handout B-3
Transparancies # 27

Instructional Approach:

Lecture
Discussion
Problem Solving

References:

1. Johnson Division U.O.P., Ground Water and Wells, Johnson Division U.O.P. 1972.
2. Walton, William G., Groundwater Resource Evaluation, McGraw-Hill, 1970.
3. Steel, Ernst W., Water Supply and Sewerage, McGraw-Hill, 1970.
4. Campbel, M. D. & Lehr, J. H., Well Water Technology, McGraw-Hill, 1973.

Class Assignments:

Read handout
Solve assigned problem

Module No: –	Topic: Basic Problem Solving
Instructor Notes:	**Instructor Outline:**
Handout B-3 Transparancies #27 1. Include: a. Aquifer depletion b. Pump problems c. Well screen clogging	1. Discuss and illustrate common well problems which can be identified and/or predicted using pumping test data.
2. Include: a. Changing pumping rate 1. Lowering 2. Increasing b. Decreasing pumping time	2. Discuss well interference and illustrate action which can be taken to minimize or eliminate the interference.
	3. Illustrate how varying the pumping rate and length of time pumped can minimize the effect of a negative boundary on a pumped well.

Module No:	**Module Title:** Water Supply - Wells
	Submodule Title: Basic Well-Field Management
Approx. Time: 4 hours	**Topic:** Record File, Planning, and Contracts

Objectives:

Upon completion of this module, the participant should be able to identify:

1. What information must be included in the permanent record file.
2. How this information can be used in planning the design of a future well within the well field.
3. Advantages and disadvantages of general drilling contracts.

Instructional Aids:

Handout C-1
Transparancies #28

Instructional Approach:

Lecture
Discussion
Problem Solving

References:

1. Johnson Division U.O.P., Ground Water and Wells, Johnson Division U.O.P. 1972.
2. Walton, William G., Groundwater Resource Evaluation, McGraw-Hill, 1970.
3. Steel, Ernst W., Water Supply and Sewerage, McGraw-Hill, 1970.
4. Campbel, M.D. & Lehr, J. H., Well Water Technology, McGraw-Hill, 1973.

Class Assignments:

Read handout
Work assigned problem

Module No:

Topic:

Record File, Planning, and Contracts

Instructor Notes:

Handout C-1
Transparancies # 28

1. Include:
   - a. Drilling Records
     1. Sieve analysis
     2. Water analysis
   - b. Equipment Records
     1. Pump curves
     2. Purchase records
     3. All parts literature
     4. Maintenance record
   - c. Well Records
     1. Specifications of components
     2. Maintenance records
     3. Yield records
   - d. Aquifer Records
     1. Draw down
     2. Static water level
     3. Recovery rate
     4. Water quality records

Include:

a. Performance Contracts
b. Comprehensive-specified contracts
c. Combination contract

Instructor Outline:

1. List and discuss the information which must be included in the permanent record file in order to adequately plan a new well.

2. Discuss the use of this record file in planning the design, placement, and overall effect of future wells in the well field.

3. Give students a problem where a model record file is used to plan the design, placement and effect of a new well.

4. Discuss the basic contract types including advantages and disadvantages of each and how bids are affected by design and specifications.

Module No:

Module Title:
Water Supply - Wells

Submodule Title:
Basic Well-Field Management

Approx. Time:
1½ hours

Topic:
Well to System (Connection and Evaluation)

Objectives:

Upon completion of this module, the participant should be able to:

1. Illustrate well placement with respect to water tower.
2. Evaluate a water system with respect to number of wells and capacity of each.
3. Identify the effect of well efficiency on total cost of water production.

Instructional Aids:

Handout C-2
Transparancy # 29 and # 30

Instructional Approach:

Lecture
Discussion
Problem Solving

References:

1. Johnson Division U.O.P., Ground Water and Wells, Johnson Division U.O.P. 1972.
2. Walton, William G., Groundwater Resource Evaluation, McGraw-Hill, 1970.
3. Steel, Ernst W., Water Supply and Sewerage, McGraw-Hill, 1970.
4. Campbel, M. D. & Lehr, J. H., Well Water Technology, McGraw-Hill, 1973.

Class Assignments:

Read handout
Work assigned problem

Module No:	Topic: Well to System (Connection and evaluation)

Instructor Notes:	Instructor Outline:
Handout C-2 Transparancies #29 & # 30	
1. Emphasize differences and similarities in water flow	1. Discuss and illustrate well-to-tower placement including: a. Well to tower only b. Well to tower and distribution system directly c. Multiple wells
	2. Discuss and illustrate the relationship of number, placement and size of wells to toal capacity of system.
	3. Discuss the effect of well efficiency on total cost of the system with respect to water production capacity.

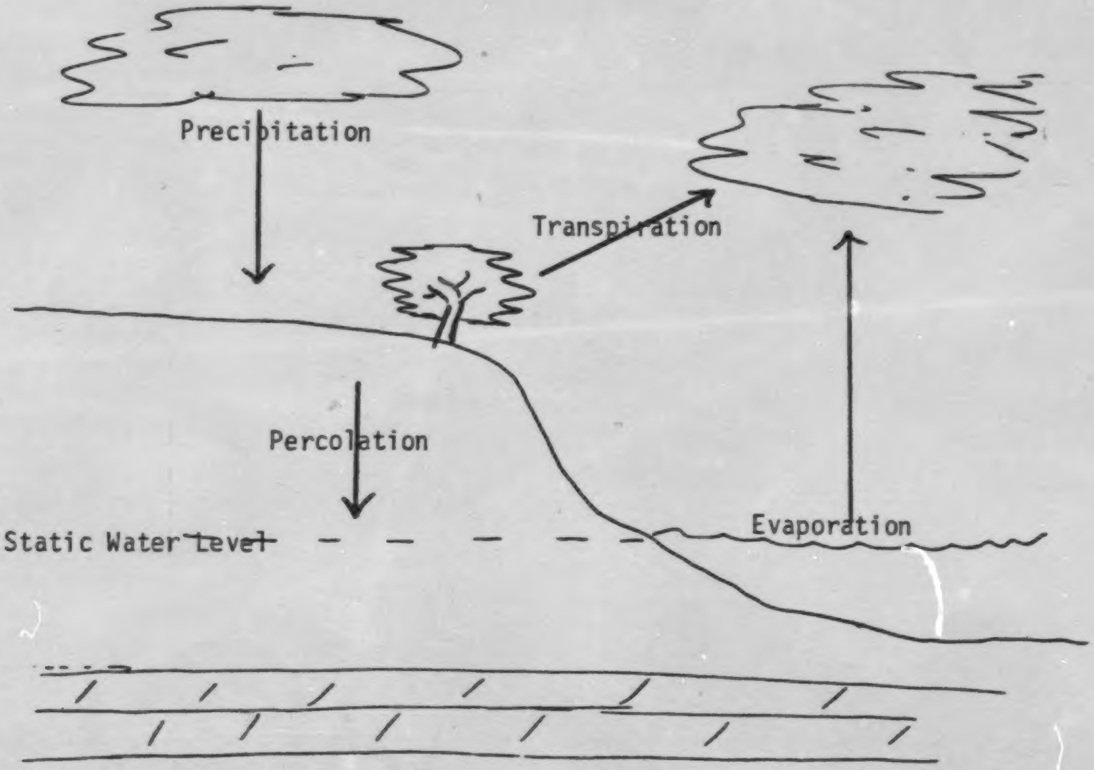
WATER MOVEMENT

I. INTRODUCTION

- A. Water is essential to life
- B. The first settlements were along water ways due to ready accessibility
- C. Water Supply
  - 1. Surface water makes up 3% of earth's fresh water
  - 2. Ground water makes up 97% of earth's fresh water
  - 3. Replenishment
    - a. Ground water accumulates over a period of centuries
    - b. Surface water, water replaced 31 times in average year

II. MOVEMENT OF WATER

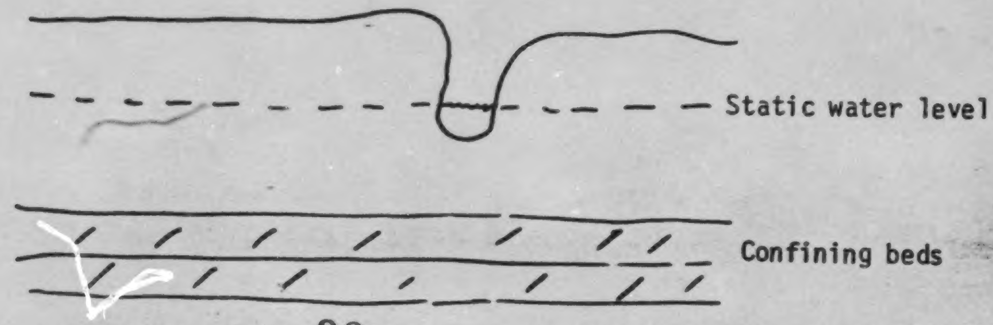
- A. Hydrologic cycle - earth's water cycle


Precipitation
Transpiration
Percolation
Evaporation
Static Water ~~Level~~

1. Terminology
   a. Precipitation is the condensation of water in atmosphere and is the earth's source of fresh water supply.
   b. Evaporation is the result of sun's radiation on open water where the heat of the sun leads to vaporization.
   c. Transpiration is the result of sun's radiation on plants and is similar to evaporation.
   d. Percolation is the movement of water through the upper ground levels to the capillary fringe.
   e. Static water level is the level of water saturation in the ground since water does seek its own level.
2. Forces affecting the hydrologic cycle include
   a. Radiation - evaporation & transpiration
   b. Gravity - precipitation, runoff & percolation
   c. Capillarity & molecular attraction - percolation

B. Movement of water to aquifer
1. The aquifer is the water bearing geologic formation
2. Formations affecting movement include slope of the ground, faults, impervious formations, vegetation, and capillary action.

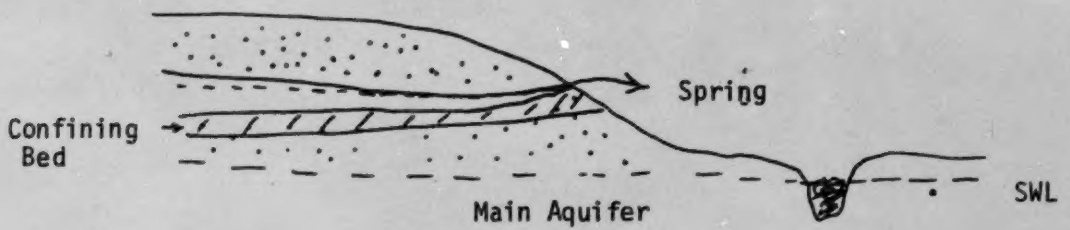
C. Aquifer - types
1. Water table - unconfined



a. Static hydrolic head - depth from static water level to depth in question.

b. Streams above aquifer can be affected so they drain to the aquifer or gain water from it. Also streams can flow periodically with runoff only or be unaffected by the aquifer below.

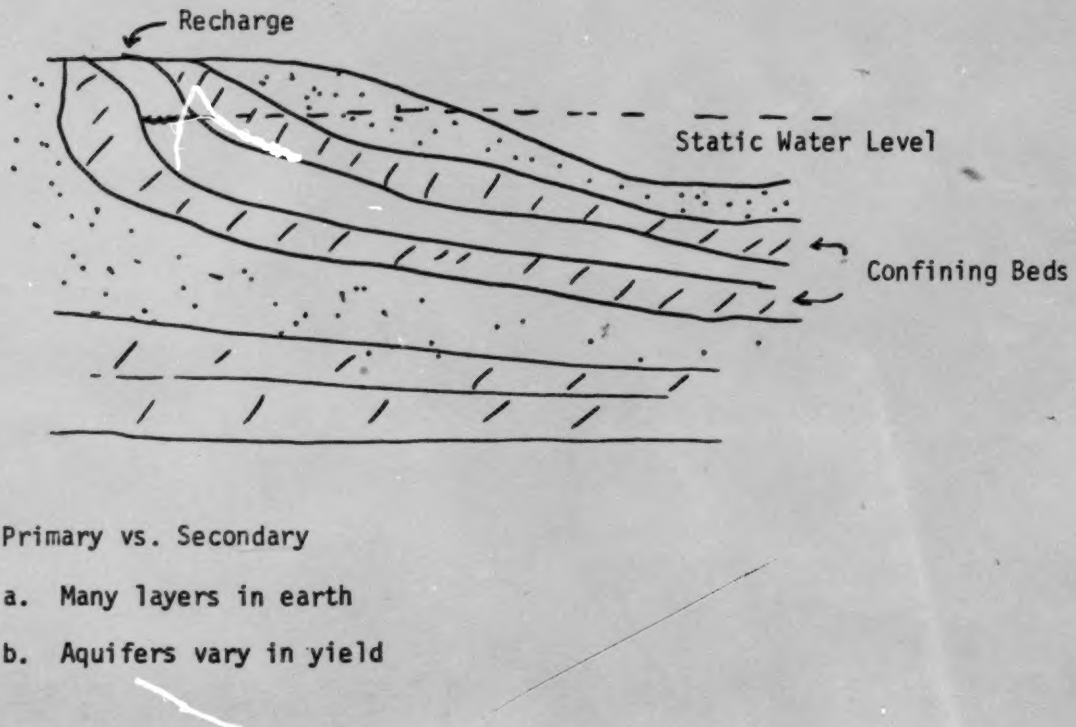
c. Perched water table


Spring
Confining Bed
Main Aquifer
SWL

2. Artisian - Upper and lower confining beds

a. Water compresses

b. Pressure to lift to static water level


Recharge
Static Water Level
Confining Beds

3. Primary vs. Secondary

a. Many layers in earth

b. Aquifers vary in yield

III. AQUIFER POLLUTION

A. Pollution can enter the aquifer through many areas including

1. Runoff entering old well. To prevent this seal the top or pull casing and allow to cave in if formation unconsolidated.
2. Runoff entering unsealed wells. Also a problem are damaged seals due to subsidence, desication of grout, and breaks in discharge pipes.
3. Aquifer mixing through well
4. Other sources of pollution include solid waste landfills, blowouts in oil and natural gas exploration, and evaporation pits of oil field brines.

IV. EXPLORATION METHODS

A. First research must be done to locate and study geological maps, and existing area well data, and make water table map.

B. Test hole may be drilled to obtain direct data on various strata, information on water quality of the various aquifers, and a drilling time log.

C. Geophysical logging will give indirect data on subsurface formations

1. Bore hole methods include electric logging, and gama ray logging.
2. Surface methods include electrical resistivity and refraction seismograph.

V. MOVEMENT OF GROUND WATER

A. Aquifer formation (rock types) include

1. Sedimentary rock which makes up 5% of rock in earth's crusts but hold 95% of earth's ground water.

a. Hard sedimentary rock includes

1. Limestone which is a variable water bearer due to extent of weathering and amount of water which has flowed through it as water dissolves the limestone ($Ca\ CO_3$).
2. Clays and shales which are poor water bearer
3. Sandstone which is a good water bearer; however the degree of cementing is proportional to the yield.

b. Soft sedimentary rock include sand & gravel. On the whole, it is the best aquifer material and usually a mixture of sand and gravel sizes.

c. Factors influencing water bearing properties of sedimentary rock include weathering, Mechanical (Desinigration) and Chemical (Decomposition), type of rock, mode of transportation and distance carried, and environment of deposition.

2. Igneous rock originated as molten materials which cooled and solidified. Basalt lava is an example. There are two types of igneous rock: Intrusive (deep slow cooling rock) which is a very poor water bearer and Extensive (ejected materials) which is a variable water bearer.
3. Metamorphic rock which are igneous and sedimentary rock altered by heat and pressure and are generally poor water bearers.

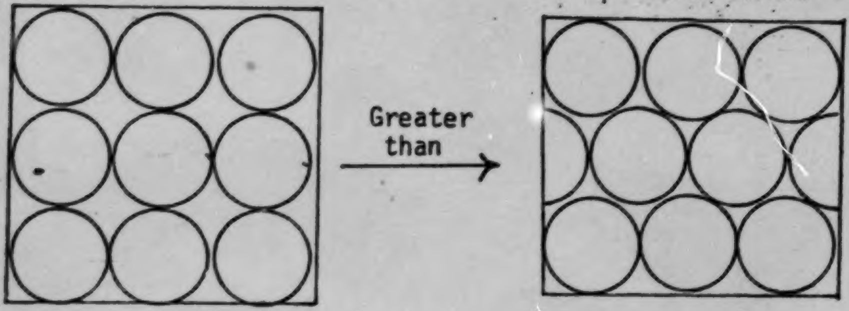
B. Aquifer Functions

1. Storage is the aquifers first function

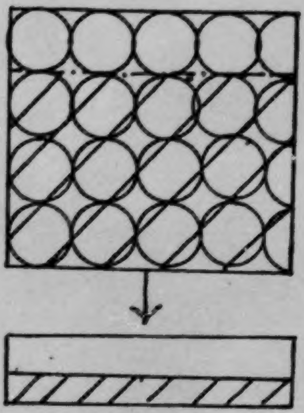
a. Porosity is defined as the portion not occupied by rock. It indicates how much water the formation will hold and is affected by partial uniformity and arrangement.

   b. Specific yield is how much water aquifer will yield when drained by gravity. That water which is retained is the specific retention.

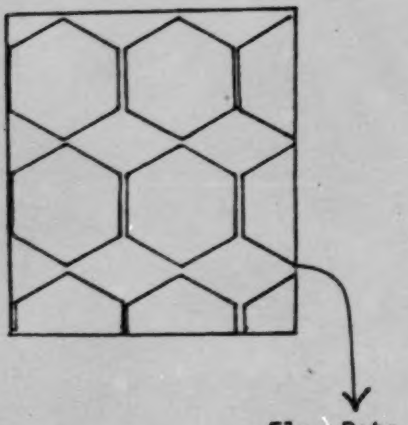
2. The aquifer also serves as a water conduit.
   a. Permeability is the capacity of the yield when a difference in head occurs. Change in permeability is proportional to change in difference of head and is affected by the particle size.
   b. Transmissibility is the rate of flow in gallons per day through the aquifer.
3. Diagrammatically



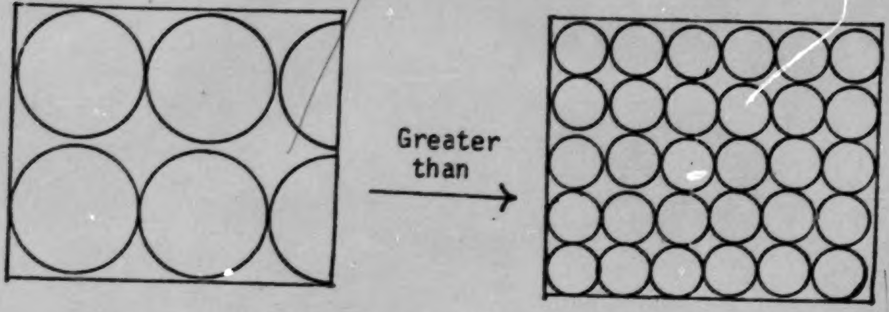
POROSITY



SPECIFIC YIELD



TRANSMISSIBILITY



PERMEABILITY

WATER WELLS

I. WELL DESIGN - COMPONENTS AND FUNCTION

A. The casing acts as retaining well which may vary from top to bottom depending on the formations penetrated.

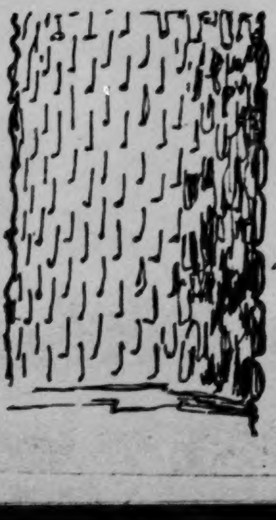
   1. Doubling the diameter only increases yield by 8 - 15%, therefore the size is chosen to accommodate pump and assure hydrolic efficiency of screen.

B. The well should be completed to bottom of tapped aquifer in order to utilize more thickness yielding higher specific capacity.

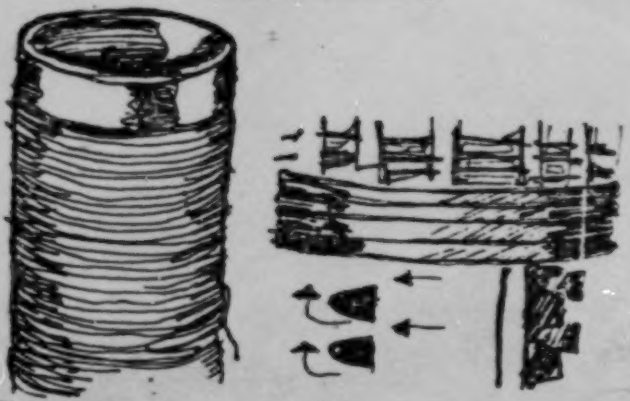
   1. This gives more drawdown yielding greater yield except with artisian aquifers where sectioned screening increase efficiency.
   2. If poor quality water is in bottom but good in top of aquifer, only the top portion is screened.

C. The screen functions as an inlet structure.

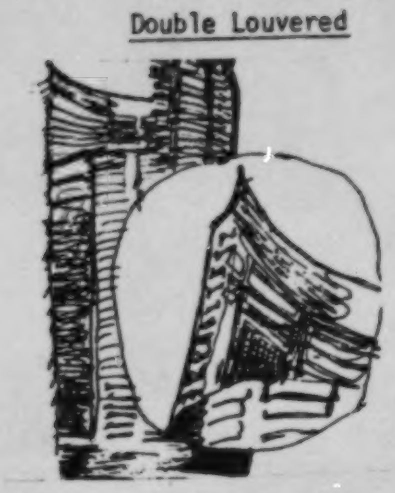
   1. No screen is used - consolidated rock since no formation support is needed.
   2. Screening is necessary with unconsolidated rock as a wall support and to keep out sand and gravel.
   3. The following screen designs are all available with varied slot size.

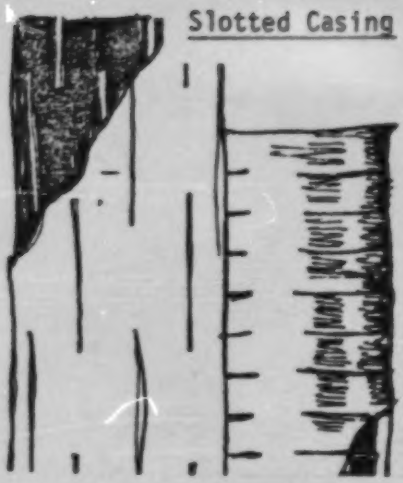


Shutter Screen



Continuous Wire Wrap





D. Completion of the well using artificial gravel pack or natural development.

1. Graded gravel is purchased with respect to sieve analysis.
   a. For artificial gravel pack choose 5 - 7 times size of the 70% size of the aquifer. This is as large as possible that will still hold back sand.
2. Procedure for completion
   a. For gravel pack the outer casing is set and the screen and well casing are set. Then the gravel is added while outer casing is pulled back.
   b. For natural development the outer casing is set and the screen and well casing are set. Then caving is allowed as the outer casing is pulled back.
3. It is necessary to gravel pack in loosely cemented sandstone and when fine unconsolidated material is present, but not in well graded gravel and rock formations.
4. To determine screen slot size remember slot size must retain 90% of sand with gravel pack but in natural wells the slot size must retain 40 - 50%. The difference due to layering in development where with gravel pack layering manmade, but in natural large particles move towards screen to block out smaller.

E. Completion vs. Usual Results Charted

Completion Method	Type of Aquifer		
	Hard Sandstone	Soft Sandstone	Sand or Gravel
Open Hole	Low cost Best method Yield effluent well	Excessive sand production unless low rate of pumping	Hole caves in
Gun or jet perforated	Inefficient plus sand production	Excessive sand plus yield decline	Inefficient
Slotted pipe	Sand production	Sand production	Inefficient
Slotted pipe with gravel pack	No sand Moderate efficiency	No sand Moderate efficiency	No sand Moderate efficiency
Continuous wire wrap	Some sand	Sand production	Sand if formation fine Best if formation course
Continuous wire wrap with gravel pack	Costly but efficient well	Sand free efficient	Sand free efficient Best if water incrusting

F. The sanitary seal must give full sanitary protection.

1. The materials most commonly used follow:
    a. Portland cement - best
    b. Portland cement + 1 - 8% bentonite - lighter
    c. Portland cement + pozzolans
        1. High sulfate resistance
        2. High salt water resistance
    d. Portland cement + perilite + bentonite
        1. Lighter
        2. Bridging material for poroses or fractured formations

   - e. Portland cement + diatomaceous earth - higher density
   - f. Portland cement + gilsonite - reduces corrosive action
2. The design must give full sanitary protection. The length requirements follow.
   - a. Minimum 20' below surface
   - b. Minimum 15' below any bypassed consolidated rock aquifer or layer
   - c. Full length in consolidated rock well
3. Placement of the sanitary seal must be as follows:
   - a. Drill as oversize borehole
   - b. Set the temporary casing
   - c. Complete and pour - or - set permanent casing, cement, telescope remaining construction and completion.
   - d. Remove temporary casing before cement hardens to allow for seal with formation

G. Pump and motor drive with respect to a need for a well pumping house.

1. The turbine pump must have a properly size motor drive for electrical efficiency and requires a pit to protect motor drive and discharge from weather and animals.
2. The submersible pump has the motor drive in the unit and is sealed at factory therefore no pit required as the pump is installed in the well completely and the discharge is usually below the frost line.

H. Valves and Meters etc.

1. Installation during construction makes for easier maintenance
2. Major pieces of interest include gate valves, flow meters, check valves, and the air line.

II. WELL CONSTRUCTION

A. Dug and augered wells are usually large diameter and shallow. Trouble occurs below SWL since auger won't carry up cuttings.

B. Cable tool and rotary drilling.

  1. Cable tool percussion consists of dropping string of tools and removing cuttings with bailer or sand pump.

    a. Speed depends on hardness of the rock, diameter of the hole, dressing of the bit, weight of tool string, and stroke rate and length of stroke.

    b. Limitations are most notable with penetration rate, depth, lack of control of fluid flow from penetrated aquifer, lack of control of borehole stability, frequent drill-line failures, and lack of experienced personnel.

  2. Rotary drilling consist of a turning bit + downward pressure.

    a. Fluid is used to relieve vertical axis stress in formation immediately below bit, remove and move cuttings to surface, segregate cuttings, maintain borehole stability, and cool the bit.

    b. Fluids used include mud (natural or bentonite, revert), water, and air.

    c. Drilling rate is affected by formation characteristics including strength characteristics, abrasiveness characteristics, drillability, the physical state of the aquifer, stress strain relationships and stickiness of formation. Drilling rate is also affected by mechanical factors; weight on bit, rotary speed, bit condition, bit diameter, and bit type: Hydrolic factors; circulation rate and friction losses: Drilling fluid properties; density, filtration, solid content, viscosity, yield point, oil content and wetting characteristics: And personal expertise.

3. Comparison of cable tool to rotary method indicates the following advantages of the cable tool method.
    a. Lower initial equipment cost
    b. Lower daily operating cost
    c. Lower transportation cost
    d. Lower rig-up time expense
    e. Drilling rates comparable in hard rock shallow wells
4. Other advantages of the cable tool method include better cutting samples, easy identification of water-bearing strata, no circulating system, minimum contamination of producing zones, and no bore hole support needed as casing driven as bore hole dug.
5. However the speed of the rotary method is much faster with large or deep wells.

C. Other methods of well drilling include jet drilling and turbine drilling.

III. DEVELOPMENT AND DISINFECTION

A. Development

1. Purpose of initial development is to correct clogging caused by construction, increases permeability, stabilize non-consolidated formations, and reducechance of the well being a sand pumper.
2. Methods of development include:
    a. Overpumping which incorporates air creating turbulence which washes out the fines, rearranges particles large to small within immediate formation, and removes the "drilling skin" on the borehole. This method alone seldom does the best job.

b. Backwashing which alternately pumps out and lets flow back. Periodically it is pumped to waste to remove sand. Since it causes flow reversals in screen it is also called "rawhiding".

c. Surging with water which uses a surge block, either a solid block for forceful surging or a valved block for light surging. This can cause clay to plaster over screen leading to a pressure differential and collapsed screen. Therefore, use with care if clay is present in the formation.

d. Surging with air which makes use of an air lift with air pipe inside pumping pipe creating 100 - 150 psi air pressure. Then the well is airlifted til water is sand free. Work must first be cycled near bottom then work can move upward.

e. Jetting which is the most effective method as it concentrates energy over a small area therefore covering screen selectively. Machinery consists of jetting tool and a high pressure pump.

B. Disinfection

1. Purpose of initial disinfection is to remove bacterial contamination introduced during construction by the casing and screen, gravel pack, components, and/or development. It does not sterilize well.
2. Chlorine is the most readily available, simplest, and most effective disinfectant available. Gas, liquid, or dry may be used but they must be in solution. Solution preparation is charted on the next page.

Desired Chlorine Strength	Quarts of bleach of various strengths per 100 gal. of water			Chlorine lb.	Dry Calcium Hypochlorite lb.
	5%	7%	10%		
50 ppm	0.4	0.3	0.2	0.05	0.07
100 ppm	0.8	0.6	0.4	0.10	0.14
150 ppm	1.2	0.9	0.6	0.15	0.20
200 ppm	1.6	1.2	1.2	0.20	0.30
300 ppm	2.4	1.7	1.2	0.25	0.40
400 ppm	3.2	2.3	1.6	0.35	0.50

3. Technique of disinfection with chlorine is as follows:
    a. Add chlorine to the well to achieve 100 ppm final solution in the well.
    b. Agitate the water in the well thoroughly.
    c. Wash and flush the component surfaces above the water level with the sterilizing solution of chlorine.
    d. Leave for a contact time minimum of 4 hours.
    e. Pump to waste until an acceptable chlorine residual is achieved.
    f. Check effectiveness by testing a sample for the presence of coliform bacteria.
    g. Repeat if necessary.

WATER WELL EFFICIENCY AND MAINTENANCE

I. EFFICIENCY

A. Well efficiency of a new well should be 80 - 90%.

1. It is defined as the actual specific capacity adjusted for well loss, and divided by the theoretical specific capacity, (dd (t)/dd (a)).
2. Inefficient wells are very expensive in terms of power costs. i.e.

   well producing 605000 gpd

   dd = 720 ft.

   Theoretical dd - 360

   Therefore, 50% efficient

   Therefore: If continuously pumped for 1 year with the 360 ft. of extra lift the added cost for operation is $20,000 (6¢ per Kwh) for that year.

B. Well efficiency reduction, if caused by reduction of permeability or turbulance due to high velocity of water entering well, can be corrected by reducing velocity. This can be done by lower pumping rate, or increase % opening of well screen. The recommended velocity of water through well screen is 0.1 ft. per second. Experience demonstrates low inlet velocity maximizes efficiency, minimizes sand pumping, and reduces rate of corrosion and incrustation.

C. Life of well is limited from day of completion unless the design permits high initial efficiency, it is pumped at the proper rate, it is readily adaptable to re-development, and preventative maintenance is completed on schedule.

D. When efficiency decreases, the first thing evident is a drop in yield

1. Causes of this include pump wear, increase in dynamic head, and interference from other wells.
2. However, the most common cause is clogging of aquifer and/or screen which is called incrustation. This is caused by deposits or accumulation of extraneous material.
3. Often incrustation is called corrosion. Corrosion is metal eaten away by water where incrustation is the collection of material from water onto the metal.
4. Water quality is proportional to incrustation and corrosion since in nature there is a delicate water mineral balance in ground water and the charge in flow caused by a well upsets this balance as the upset can lead to precipitation.
5. Even minute deposition is a serious problem. For example: 1 ppm material per day in 220 day yields 6" fully incrusted and if well pumps 500 gpm (12" well) 6 lb. per day accumulation
6. From this, it can be seen that proper and timely maintenance is essential and good record keeping is manditory. Remember, good records provide the best advice for type of maintenance which will yield the best results.

II. INCRUSTATION

A. Precipitation of minerals from the water onto the well screen is a form of incrustation.
   1. Water quality is key to predicting future problem areas including hardness - $CaCO_3$, iron, manganese, and magnesium.
   2. Chemistry of precipitation
      a. The ability of the water to carry $CaCO_3$ is proportional to the amount of CO2 dissolved since $CO_2 + H_2O$ = carbonic acid, the

amount of CO_2 dissolved is proportional to the water pressure and as the water pressure decreases, less CO_2 is held and therefore $CaCO_3$ precipitates out.

b. The chemistry of FeOH and MnOH precipitation is similar to Ca CO_3 but it is caused by a change in velocity. As velocity increases Fe OH and MN OH precipitate. Then oxidation yields hydrated oxides.

3. The rate of precipitation is proportional to the water quality and the change from normal movement. It increases in increased incrustation due to decrease in opening size leading to increase in velocity and pressure drop.

4. The treatment for incrustation from precipitation consists of using inhibited muriatic or sulfamic acid. (Inhabition aide is corrosion prevention).

   a. Muriatic Acid is the same as hydrochloric acid. Be sure to use strongest grade (27.92%).

   b. Sulfamic acid is weaker than muriatic acid therefore requiring a longer contact time but is less corrosive.

   c. Comparing the two sulfamic acid is more expensive than muriatic acid but shipping costs are lower, handling is easier and it fumes less.

5. CAUTION. The fumes formed are CO_2 and H_2S (with iron incrustation), both are very toxic and heavier than air. Therefore allow no men in pits or depressions, and provide adequate ventilation to pump house or area.

6. Procedure for inhibited muriatic acid treatment after pump is pulled and the well prepared.

a. Add acid through a plastic pipe at the rate of 2 times the volume of water in the screen. This completely fills screen and forces some into aquifer formation.

b. Agitate 1 - 2 hours. Remember the more incrusted the slower the action.

c. Remove spent acid and loosened incrustants using a bailer. (Do not use pump as acid will corrode it.) Continue till acid is cleared. Dispose of wasted water.

d. Repeat a second time. This time vigorous agitation is important as the acid will flow to cleaned areas first due to less resistance.

7. Procedure with sulfamic acid treatment after pump is pulled and the well prepared.

a. Solubility is proportional to water temperature as shown below:

Temp.	Maximum weight of dry acid per 100 gal. water	Acid concentration of saturated solution
40° F	140 lbs.	14%
50° F	150 lbs.	15%
60° F	167 lbs.	17%
75° F	190 lbs.	19%

b. Dissolve acid in tank of water and introduce into well screen using the same procedures with muriatic acid or the granular material itself can be poured into the well followed by agitation to insure complete dissolution.

c. Agitate periodically for a minimum of 2 hours. The longer time is necessary because acid is weaker.
d. Remove spent acid and loosened incrustants using a bailer and continue till acid clears again disposing of waste on ground.

B. Deposition of soil materials is second form of incrustation.
1. Formation type is key since clay and silt will pack and gravel will be cemented by Ca CO_3. Problems in this area indicate the screen openings are too small, or improper well development.
2. Chemistry of deposition is simply a cementing process which can develop rapidly.
3. Treatment is chemical using glass phosphates which act as non-foaming detergent. The step by step procedure follows:
    a. Dissolve phosphate in tank of water using burlap bag. Use 15 to 30 lbs. for every 100 gal. water in well.
    b. Add 1 lb. calcium hypochlorite for every 100 gal. water in well.
    c. Add to well the same as acid.
    d. Agitate vigorously to aid detergent action.
    e. Pump to waste till clear and repeat once.

C. Bacterial growth and slime deposits
1. Presence of iron bacteria i.e. Clonothix, Crenothrix, Leptothrix, or Gallionella. Presence of ferrious iron causes the incrustation.
2. The biology of bacterial deposits is the use of ferrious iron by bacteria which give off ferric iron and ferric hydroxide as waste. The optimum growth is at ground water temperatures and a D.O. of 0.3 - 9.0 ppm.

3. Chlorine treatment is the cheapest, most readily available, and most efficient in breaking up organic slime and killing the bacteria. The procedure follows:
    a. Add the chlorine to the well through a separate plastic pipe (same as acid) to a concentration of 100 - 200 ppm.
       Note: 30 - 40 lbs. over a 10 - 12 hr. period is adequate for a large well.
    b. Add 50 - 100 times the volume of water standing in the well to force the chlorine into the formation.
    c. Agitate vigorously and pump to waste till clear.
    d. Repeat 2 or 3 times
        1. Alternate with acid to aid in breaking up iron deposits.
        2. Alternate with glassy phosphates to aid in breaking up slime.

D. Although there is no cure for incrustation, the following measures will delay the problem as long as possible.
    1. Maximum inlet area to reduce velocity to a minimum
    2. Reduce pumping rate to reduce oxidation to a minimum
    3. Divide pumping load between several wells if necessary and
    4. Periodically clean the screen every 8 - 12 Mo. to eliminate serious clogging problems, and lengthen lifespan of pump. This then can be done at convenience rather than emergency, therefore better job is done due to available time factor.

III. CORROSION

A. Well design key factor in corrosive water since corrosion is the attack of the metals by the water.

B. Corrosion limits well life in 3 ways:

1. Screen slot increases leading to sand pumping
2. Strength reduction followed by bollapse
3. Redeposition of corroded products leading to blockage of screen

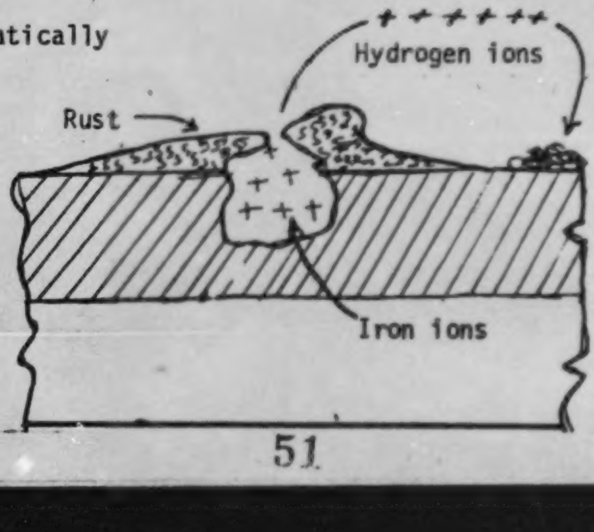
C. Rate of corrosion with respect to properties of the metal is proportional to chemical affinity, oxidation passivity, properties of corrosion byproducts, composition of the metal, stains due to heating and cooling, original state of the metal, and galvanic relationships.

D. Rate of corrosion with respect to ground water quality is proportional to pH (ground water acidity), oxidizing characteristics, entrance velocity, and temperature.

E. Indicators of corrosive ground water are acid pH (< 7.0),High dissolved oxygen, hydrogen sulfide present, high TDS, High CO_2, Chloride present and temp.

F. Types of corrosion include

1. Direct chemical attack which uniformly destroys the metal and
2. Dezincification (Selective Corrosion) which removes 1 metal from alloy and leaves spongy condition which can suddenly collapse.
3. Galvanic corrosion which occurs when 2 metals or different areas of the same metal are electrically connected in a conductive solution
    a. Diagrammatically



b. Galvanic Series

Galvanic Series

Corroded end	Magnesium alloys Magnesium
	Zinc
	Aluminum 25
	Cadmium
	Aluminum 17 ST
	Steel, iron, cast iron
	Ni-resistant Chromium - iron
	18 - 8 Stainless Steel (active)
	Lead, tin, lead-tin solders
	Nickel, Inconel (active)
	Bronze, Monel Brass, copper
	Silver solder
	Nickel, Inconel (passive)
	Chromium - iron (passive)
	18 - 8 Stainless steel (passive)
	Silver
Protected end	Gold, platinum

H. There is no treatment for corroded screens except to replace the screen. – Therefore it is essential to delay or prevent with proper initial design.

IV. PUMP WEAR

A. Premature wearing can be caused by

1. Sand pumping where sand acts as grinding compound which pits and wears impellor causing increased friction leading to less water moved.
2. Improper adjustment which increases metal - metal friction causing excessive wear on impellor blades leading to less depth to blades and less water moved.

B. Use of a pump will always lead to wear due to friction and mechanics.

C. Prevention of premature wear is best accomplished by proper adjustment and proper design to reduce or eliminate sand pumping.

V. OPERATING AND MAINTENANCE RECORDS

A. Must keep records

1. Your well will drop in production with use and records will give clue to why.
2. Permanent record file for each well must include:
   a. Test hole logs and location maps
   b. Sieve analysis from test holes and production well
   c. Water analysis from test holes and production well
      1. This must be done periodically in production well as water quality will change with time and checks must be made to monitor the entrance of pollution.
      2. The frequency depends on well location and water quality
   d. All geologic data
   e. Blueprint with accurate, as built, dimensions of well and components

f. Original pump test records

g. Pump spec. sheets & design & parts list

h. Pump performance curves

i. Details of repairs including when done, by whom, and what done.

j. Maintenance activities

3. Establish monitoring program and keep record of results

a. Once a year at low demand (i.e. Feb.)

1. Run short (2 hr.) pumping test rate to give time drawdown (change in water level in well with respect to pumping time) measure static water level measurement, and

2. Measure specific gravity.

b. Every 4 Mo.

1. Record static water level after pump off 2 hr.

c. Record amount water used weekly

d. Once a yr. at high demand (summer)

1. Measure time drawdown and yield

2. Measure distance-drawdown in observation wells are available

e. Periodic, bacteriological, and chemical analysis

f. Yearly meter calibration and power consumption check

g. Once a yr. test pump to develop head capacity curve for comparison with original.

B. Well Equipment

1. Drawdown tube (or stilling well or electric probe) permanently installed reflect H_2O level inside casing.

2. Meter (to measure flow)

3. Check valve

4. Gate valve (aids in removing pump

5. Bypass system (to pump to waste)

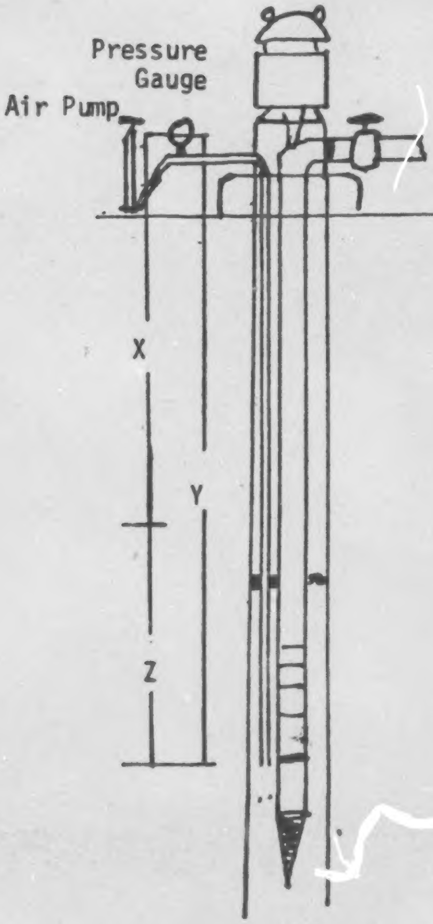
6. Pressure gauge (discharge pressure) mount over where it won't be vibrated.

7. Sampling tap on pump side of gate valve.

VI. MAINTENANCE TEST PROCEDURES

A. Measurement of water level includes measurement of static water level, drawdown, and recovery rate. Methods of water level measurement include:

1. The air line method which incorporates pressurized air in a 1/4" line which is gauged so maximum pressure held is proportional to depth to water. Choice of material depends on water quality as it is permanently installed at construction.



FACTORS

X = Depth to water in feet (required).

Y = Length of air line in feet (known).

Z = Air line water pressure (pressure gage reading). This must be in feet of water. Should gage read in pounds then convert to feet by multiplying by 2.31.

FORMULA

$X = Y - Z$

2. The electric sounder where an electrode is lowered on a calibrated wire which actuates a flow of electricity (indicated by volt meter) upon touching water. This is not a permanent installation.
3. The wetted tape method is just that. A chalked line is dropped and the distance from the end to the top of washed off chalk measured.

B. Measurement of the yield of the well can be done by a variety of methods including:

1. Volumetric where an amount of water is allowed to flow into a container while being timed with stopwatch. Then gpm are calculated by the formula volume in gallons/time in minutes = gpm (Q).
2. Use of weirs with or without end constrictions where Q = 1495 x L x H x /H
3. Metered flows which directly read the yield (Q) in gpm.

C. Recording all data must be accurate and include well identification, time since pumping began or ended and corresponding depth to water, the yield during that particular test, methods used, and personnel involved.

VII. BASIC TROUBLE SHOOTING

A. Records are best aid in Basic Problem Solving since they yield:

1. Periodic water analysis including type of incrustation and corrosivity of the water.
2. Drawdown and static water level measurements which aid in identifying pump problems, corrosion or incrustation, and a depleting aquifer.
3. Calculation of apparent storage coefficient when combined with drawdown give good indications of problems with pump, screen, and aquifer.
4. These measurements are only useful in comparative analysis as you are looking for significant changes.

B. Example Problems

1. In depleting aquifer the yield decreases due to increase in head because the static water level decreases due to less available water.

TYPICAL DATA SHEETS COMPARED

1970 Measurements

1. Date - August 23, 1970
2. Yield = 300 gallons per minute

   Test method - meter
   (Calibrated 6 - 9 - 69)
3. Static water level = 73'

   Test method - air line

   Time since pumping stopped - 2 hrs.
4. Drawdown

Time in Minutes	Drawdown in Feet
5	19.2'
25	22.5'
50	25'
150	26'
500	29'

1975 Measurements

1. Date - August 10, 1975
2. Yield = 210 gallons per minute

   Test method - meter
   (Calibrated 7 - 1 - 75)
3. Static water level = 95'

   Test method - air line

   Time since pumping stopped - 2 hrs.
4. Drawdown

Time in Minutes	Drawdown in Feet
5	19.3'
25	22.4'
50	25'
150	26.2'
500	29'

2. In incrustation of screen and aquifer the yield drops due to less water entering screen, draw down in pumped well increases because water enters the well slower through the smaller screen openings, and the calculated storage coefficient decreases.

TYPICAL DATA SHEET COMPARED

1968 Measurements

1. Date - August 14, 1968
2. Yield - 420 gallons per minute

   Test Method - meter
   (calibrated 6-4-68)
3. Static water level - 102'

   Time since pumping stopped - 2 hrs.
4. Drawdown

   Test Method - Air line 18" from well center.

Time in Minutes	Drawdown in Feet
5	8'
10	10'
100	12.5'
500	14.8'
1000	15.8'

5. Storage coefficient = 0.24

$$(S = \frac{0.3\ T\ t_0}{r^2})$$

1972 Measurements

1. Date - August 31, 1972
2. Yield - 250 gallons per minute

   Test Method - meter
   (calibrated 6-1-72)
3. Static water level - 102'

   Time since pumping stopped - 2 hrs
4. Drawdown

   Test Method - Air line 18" from well center.

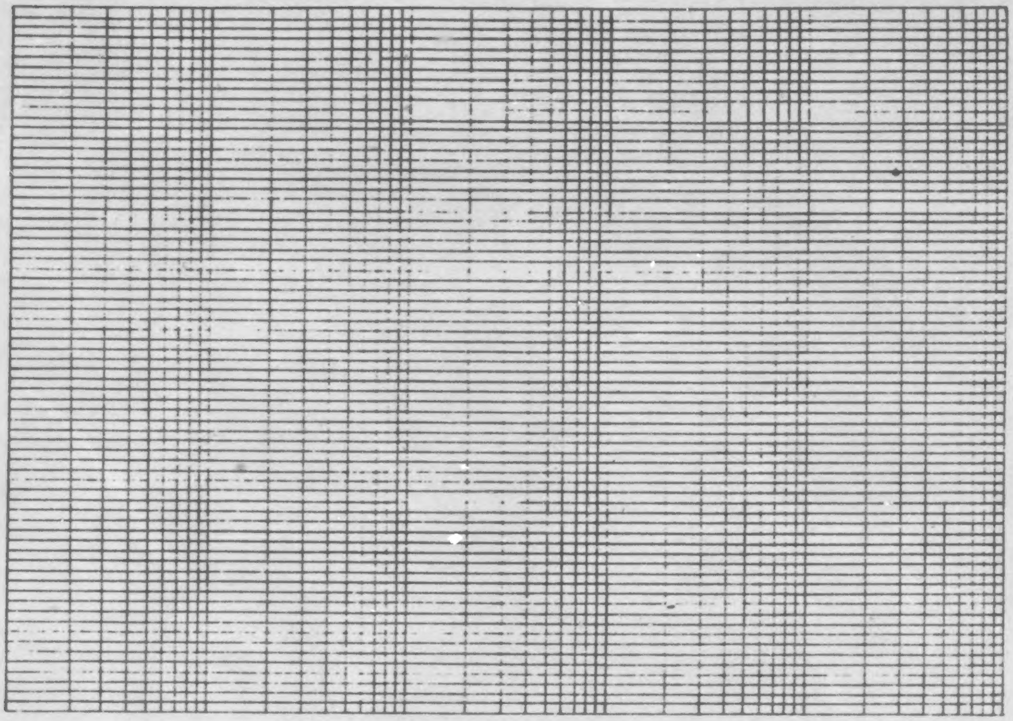
Time in Minutes	Drawdown
5	15'
10	15.5'
100	18'
500	19'
1000	19.5'

5. Storage coefficient = 0.00002

$$(S = \frac{0.3\ T\ t_0}{r^2})$$

Practice Problem

1. Plot data from page 14 for both 1968 and 1972 on the graph provided below. (Note the relationship of the lines to one another.)
2. Calculate storage coefficients from your plot. (Formula given below).



$$S = \frac{0.3T\ to}{r^2}$$

S = Storage coefficient

to = Maximum pumping time showing zero drawdown in minutes

r = Distance from center of well to point of measurement in feet

$$T = \text{Transmissibility} = \frac{264 \times \text{yield in gpm}}{\text{Change in drawdown over 1 log cycle}}$$

3. With loss of pump efficiency the yield drops because the pump lifts less water, the drawdown in pumped well decreases because the pump is removing less water, and the calculated storage coefficient remains unchanged.

TYPICAL DATA SHEET COMPARISON

1972 Measurements

1. Date - August 23, 1972
2. Yield - 240 gallons per minute

   Test Method - Meter
   (calibrated 6 - 4 - 72)
3. Static water level = 143'

   Test Method - Air Line

   Time since pumping stopped - 2 hrs.
4. Drawdown

   Test Method - Air line/8" from well center

Time in Minutes	Drawdown in Feet
5	6.5'
10	7.5'
50	11.5'
100	13'
500	16'
1000	17.5'

5. Storage coefficient = 0.22

$$\left(S = \frac{0.3\ T\ t_o}{r^2}\right)$$

1973 Measurements

1. Date - August 10, 1973
2. Yield - 210 gallons per minute

   Test Method - Meter
   (calibrated 5- 30 - 73)
3. Static water level = 145'

   Test Method - Air Line

   Time since pumping stopped - 2 hrs.
4. Drawdown

   Test Method - Air line/8" from well center

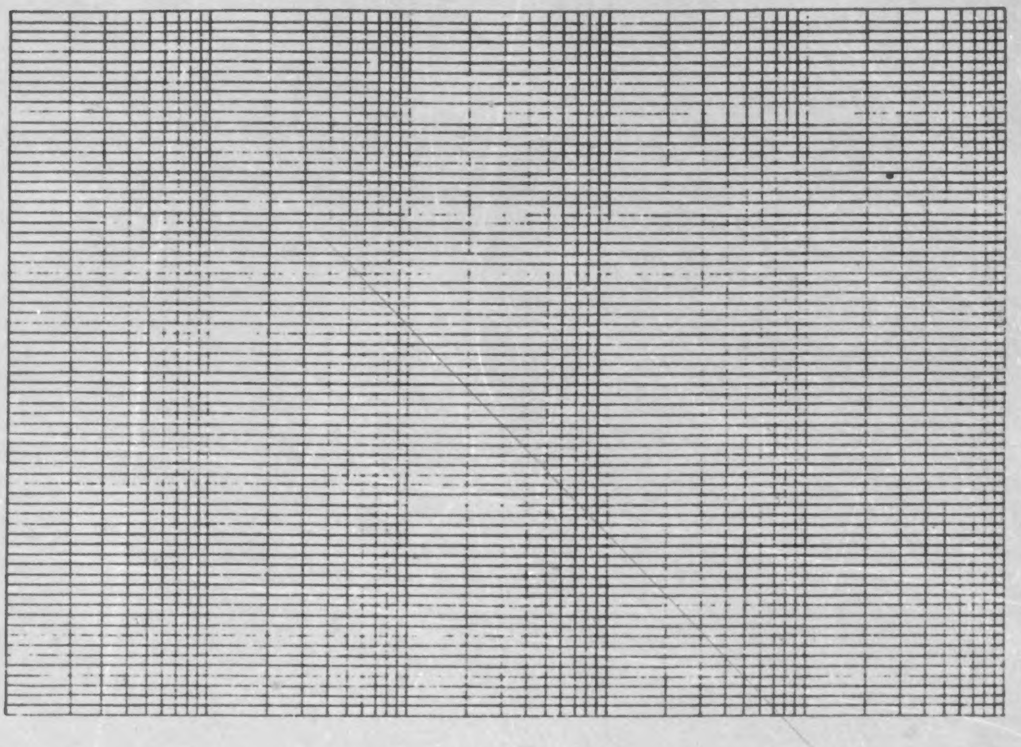
Time in Minutes	Drawdown in Feet
5	5.5'
10	6.5'
50	10'
100	11'
500	14'
1000	15'

5. Storage coefficient = 0.27

$$\left(S = \frac{0.3\ T\ t_o}{r^2}\right)$$

Practice Problem

1. Plot data from page 16 for both 1972 and 1973 on the graph provided below (Note the relationship of the lines to one another.)
2. Calculate the storage coefficients from your plot (formula given below).



$$S = \frac{0.3T\ to}{r^2}$$

S = Storage coefficient

to = Maximum pumping time showing zero drawdown in minutes

r = Distance from center of well to point of measurement in feet

T = Transmissibility = $\frac{264 \times \text{yield in gpm}}{\text{Change in drawdown over 1 log cycle}}$

Practice Problem

Given the following pumping test dada, determine if there is an impending problem and if so determine if the pump is going bad, if the well screen is clogging, or if the aquifer is depleting.

1975 Data

Static water level = 100'
Yield of well 500 gpm
Pumping test data:

Time in Minutes	Drawdown in feet
5	19'
10	20'
25	22.5'
50	25'
100	25.5'
500	29'
1000	31'

1976 Data

Static water level = 99'
Yield of well = 300 gpm
Pumping test data:

Time in Minutes	Drawdown in feet
5	21'
10	22.5'
25	24
50	25.5
100	27'
500	30'
1000	31.5'

General Information

Well diameter = 24"

Depth = 340'

Drawdown tested by airline method at outer edge of well

Handout B-1

GROUND WATER MOVEMENT

Ground water, under normal conditions, moves very slowly, or not at all, through the various ground formations. This movement is affected by porosity, permeability, transmissibility storage coefficient recharge and specific yield of the aquifer.

Porosity = $\frac{V\ voids}{V\ total}$ = % of total that is void space.

Permeability = K = ease with which fluid can move through the matrix, dependent on interconnection of void spaces.

Units = volume/time/area
= gpd/ft.^{2} Meinzer US
= cm^3/sec/cm^2
(1 cm^3/sec/cm^2 = 21,200 gpd/ft^2)

Transmissibity = T = coefficient of transmissibility
Includes aquifer thickness - K x m where m = thickness

Units = volume/time/area (width)
= gpd/ft (width of aquifer)
or 1/day/meter (liter per day/meter width)
(1 pgd/ft = 12.4 1/day/meter)
Important in calculating gross aquifer flows

Storage coefficient = S (dimensionless)

a. Confined aquifer range = 1×10^{-1} to 1×10^{-5}
Amount of water in storage released from a column of aquifer with unit cross section under a unit decline in head. Considers compressibility of water and aquifer.

b. Unconfined aquifer range = 0.3 to 1×10^{-1}
Amount of water drained by gravity from a unit cross section under a unit decline in head.

Specific Yield

Darcy equation = Q = KIA

Q = quantity of water/unit time = gpd
K = hydraulic conductivity = permeability

I = hydraulic gradient = $\frac{\text{head loss}}{\text{distance}} = \frac{h}{T}$

A = cross sectional area through which the water is moving = m (thickness of aquifer) times w (width of aquifer or width of interest)

SEDIMENTARY ROCK

FINE UNIFORM SAND

Porosity - good
Permeability - good
Storage coefficient - good
Specific yield - good

Expected well yield
Good

COARSE UNIFORM GRAVEL

Porosity - good
Permeability - very good
Storage coefficient - good
Specific yield - very good

Expected well yield
Very good

MIXED SAND AND GRAVEL

Porosity - fair
Permeability - good
Storage coefficient - good
Specific yield - good

Expected well yield
Fair to Good

CLAY

Porosity - very good
Permeability - poor
Storage coefficient - poor
Specific yield - poor

Expected well yield
Poor

LIMESTONE

Porosity - variable
Permeability - variable
Storage coefficient - variable
Specific yield - variable

Expected well yield
Variable

IGNEOUS ROCK

EXTRUSIVE (BASALT)

Porosity - variable
Permeability - variable
Storage coefficient - variable
Specific yield - variable

Expected well yield
Variable

INTRUSIVE (GRANITE)

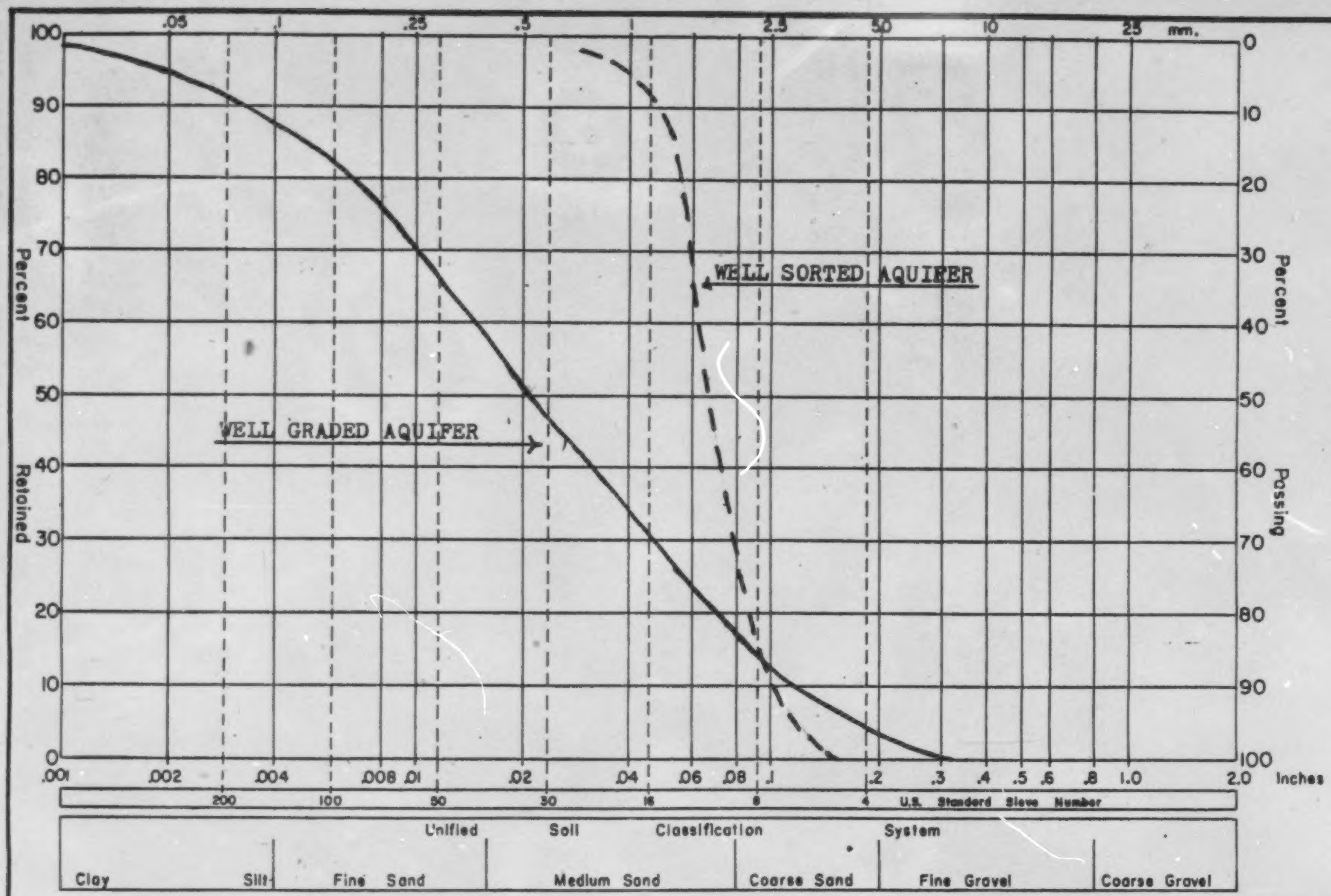
Porosity - poor
Permeability - poor
Storage coefficient - poor
Specific yield - poor

Expected well yield
Poor

METAMORPHIC ROCK

Porosity - poor
Permeability - poor
Storage coefficient - poor
Specific yield - poor

Expected well yield
Poor



SIEVE ANALYSIS

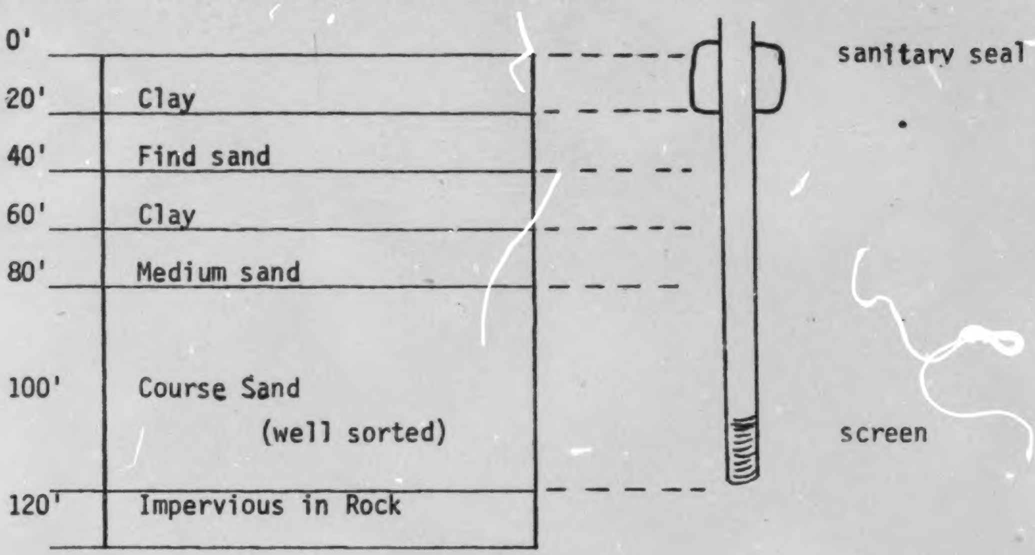
For: ______________________ Well No. ______________

Project: ______________________ Depth: ______________

Practice Problem

Given:

1. Basic Analyses
   1. Rolling hills
   2. No well developed drainage
   3. High seasonal rainfall
   4. Major river near
2. Nearby well showed the following drilling analysis:


0'
20'
Clay
40'
Find sand
60'
Clay
80'
Medium sand
100'
Course Sand
(well sorted)
120'
Impervious in Rock
sanitary seal
screen

3. Design of planned well shown at right of drilling log

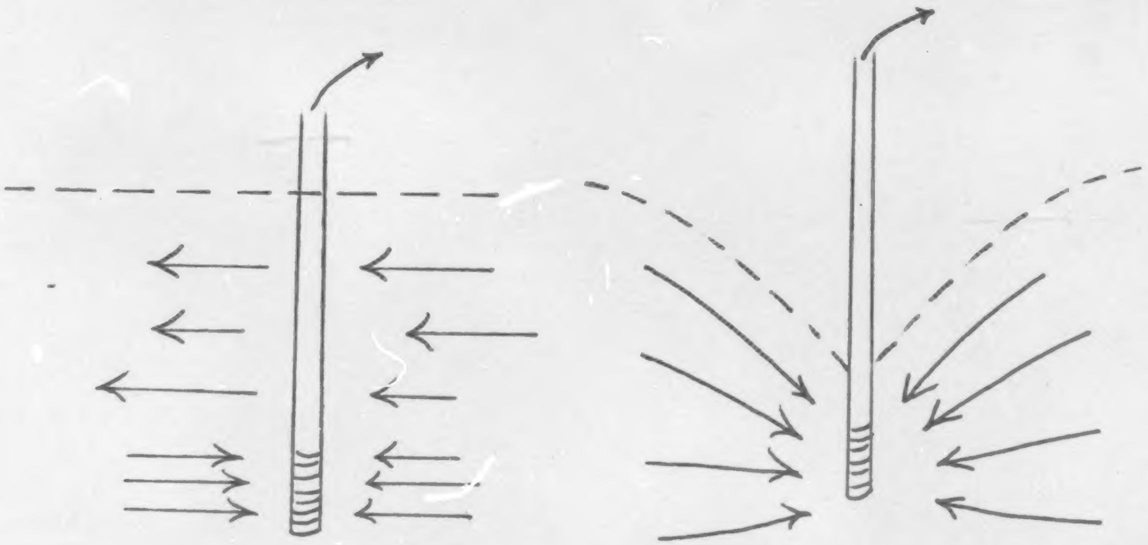
Determine expected well yield.

DETERMINING WELL PERFORMANCE

Pumping tests can be used to determine well performance. Plotting the data on semi-log paper can be done in such a way as to relate several characteristics. Length of pumping time, pumping rate, and well spacing are only a few factors which can be related to drawdown. First let us examine drawdown itself and its relationship to distance and time.

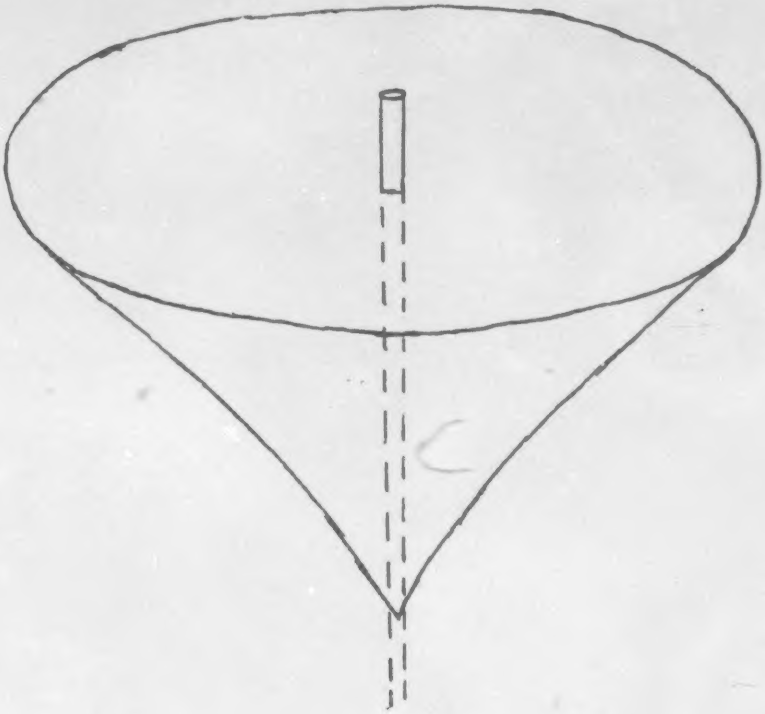
Drawdown

When a well is drilled and pumping begins, groundwater in the area of the well is removed from the aquifer. If water is being withdrawn from the aquifer, at a faster rate than what can be supplied at the point of entry, a change in the directional flow will occur.



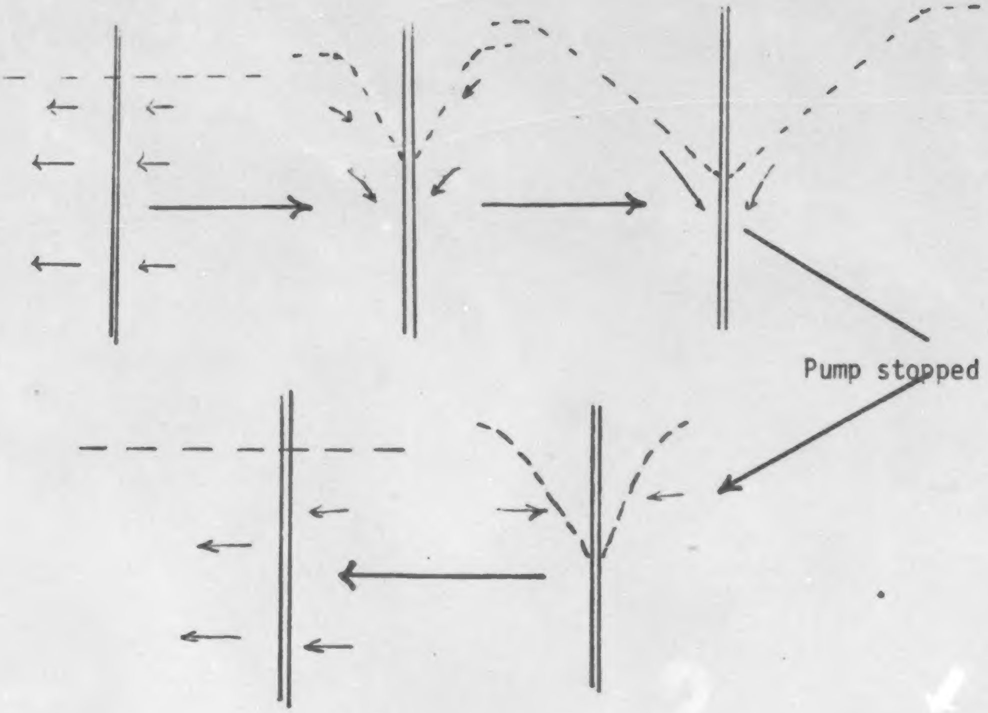
Therefore what develops is an actual draining of a water table aquifer or a noticeable drop in static pressure of an artisian aquifer.

This change in flow direction creates a hydrolic gradient (cone of depression) surrounding the well.



This cone develops initially with respect to pumping rate and recharge and will continue to widen and deepen with respect to pumping time until: (1) Natural discharge equals pumping rate, (2) The cone intercepts a body of surface water from which water entering equals the water being removed, or (3) The precipitation above the cone of depression equals the amount being removed from the well. At this point the cone will stabilize and pumping can continue indefinitly without change in the cone of depression. However, it must be noted that when pumping stops the cone will begin to fill in as the water once again returns to its natural flow.

Diagrammatically:



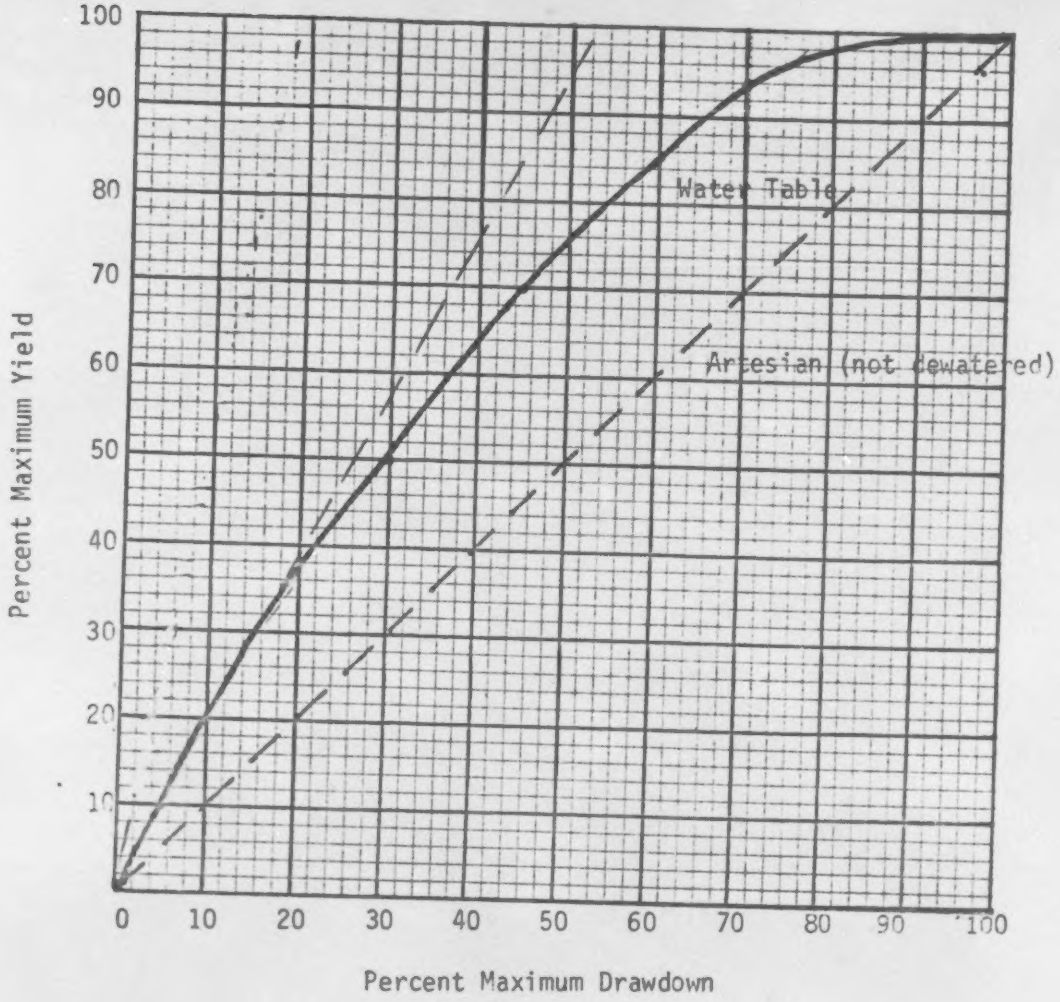
Drawdown then can be described as the measurement of this change in water level in the well being pumped and can be observed in the surrounding formation by the use of observation wells.

Drawdown in the well being pumped can be measured with respect to time since pumping began at a specified radius from the well. This information then is referred to as Time-Drawdown data and is useful in determining effect of boundaries, pumping rates, etc.

Drawdown in the surrounding formation (the extent of the cone of depression) can also be measured with respect to distance from the center of the pumped well at a given time since pumping began. Thus it is termed Distance-Drawdown. The data from these measurements aids in determining proper well spacing.

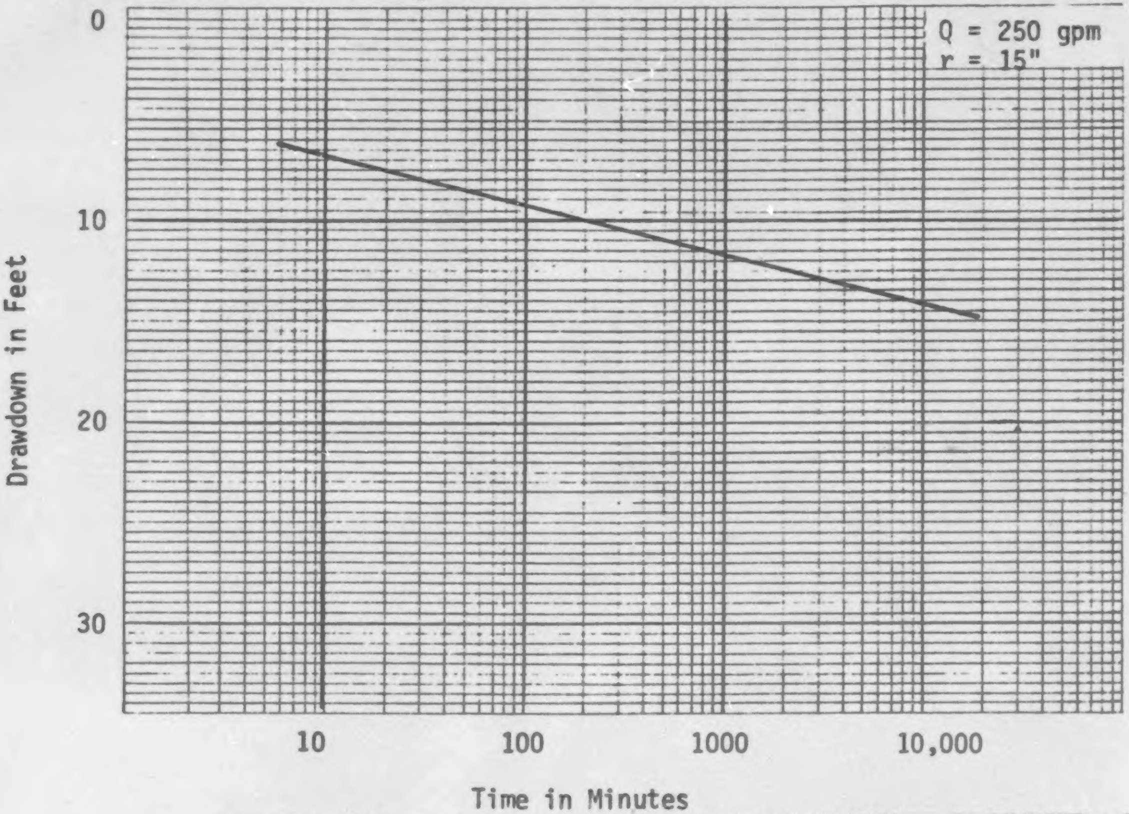
Well Diameter - Drawdown - Yield

Well Diameter	Comparable % Yield Per Ft. Drawdown			
6"	100			
12"	111	100		
18"	↓	↓	100	
24"	123	111	↓	100
36"	↓	↓	111	↓
48"	137	123		111



Time and Drawdown

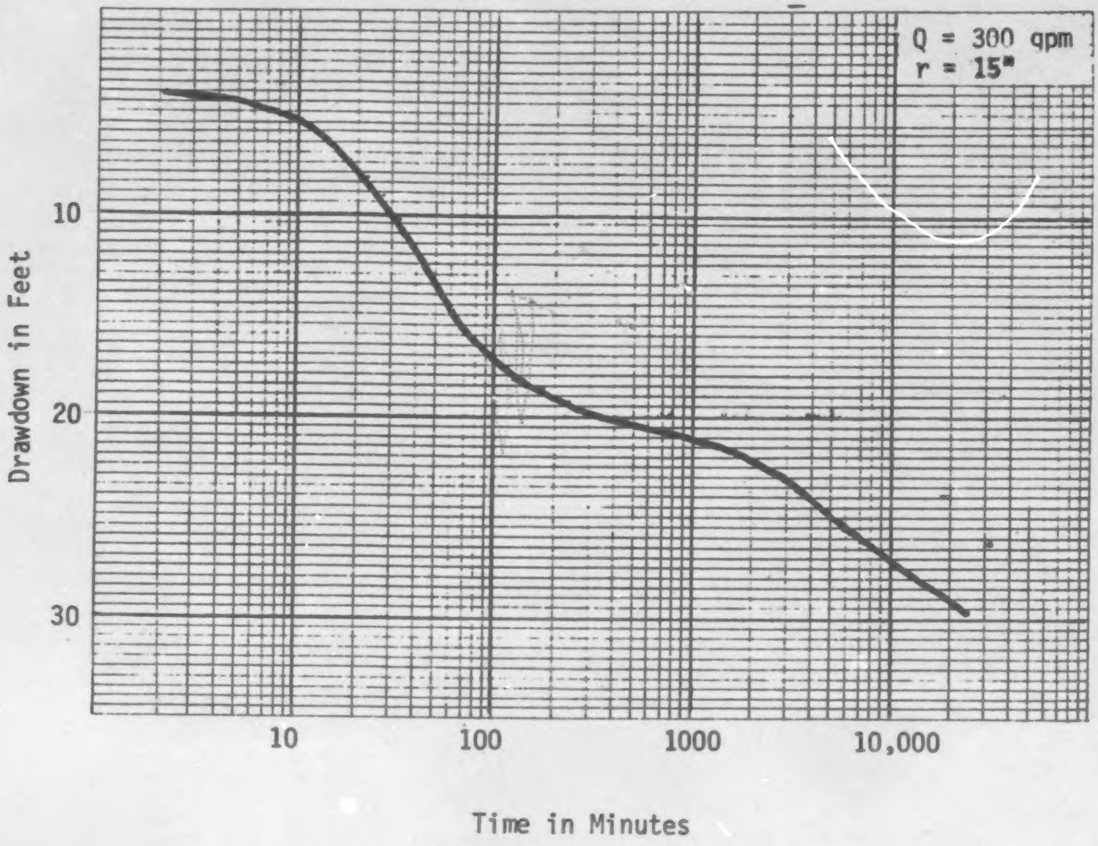
Ideally, drawdown is constant with time given a constant pumping rate. In plotting data obtained therefore one should get a straight line as shown below.



However, wells never perform to meet with the ideal conditions. Usually drawdown measurements are as follows:

Time	Drawdown	Time	Drawdown
2	4'	250	20'
5	5'	500	21'
10	5.5'	1000	22.5'
50	15.5'	2000	23'
80	17'	4000	25.5'
120	19'	10000	28'

When this data is plotted, a graph as follows if formed.



As you can see the line which ideally is straight forms an "S" shaped curve. This is due to the aquifer forming a condition similar to a partial vacuum which takes time to correct itself and continue with an accurate drawdown. The time period necessary to produce valid pumping test data will usually be 1 - 3 days for an artisian aquifer and 4 - 10 days for a water table aquifer. Therefore, one can see why it is essential to continue initial pumping tests for several days when necessary. This negative pressure effect is not seen on distance drawdown curves.

Time Drawdown with respect to pumping rate

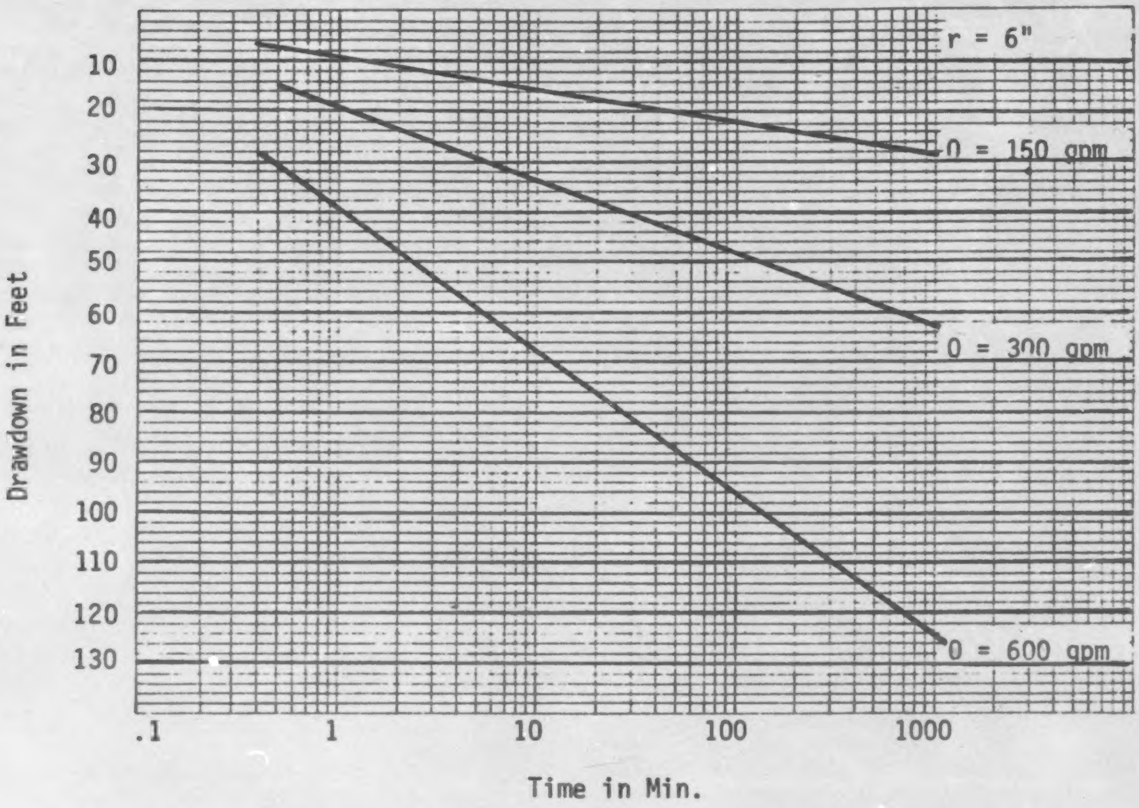
In a perfect artesian water table aquifer where no recharge occurs, drawdown is directly proportional to yield (pumping rate). As the yield is double, the drawdown (at any given distance and time) is also doubled.

Note: Q = Pumping Rate = Yield

r = Distance to center of pumped well

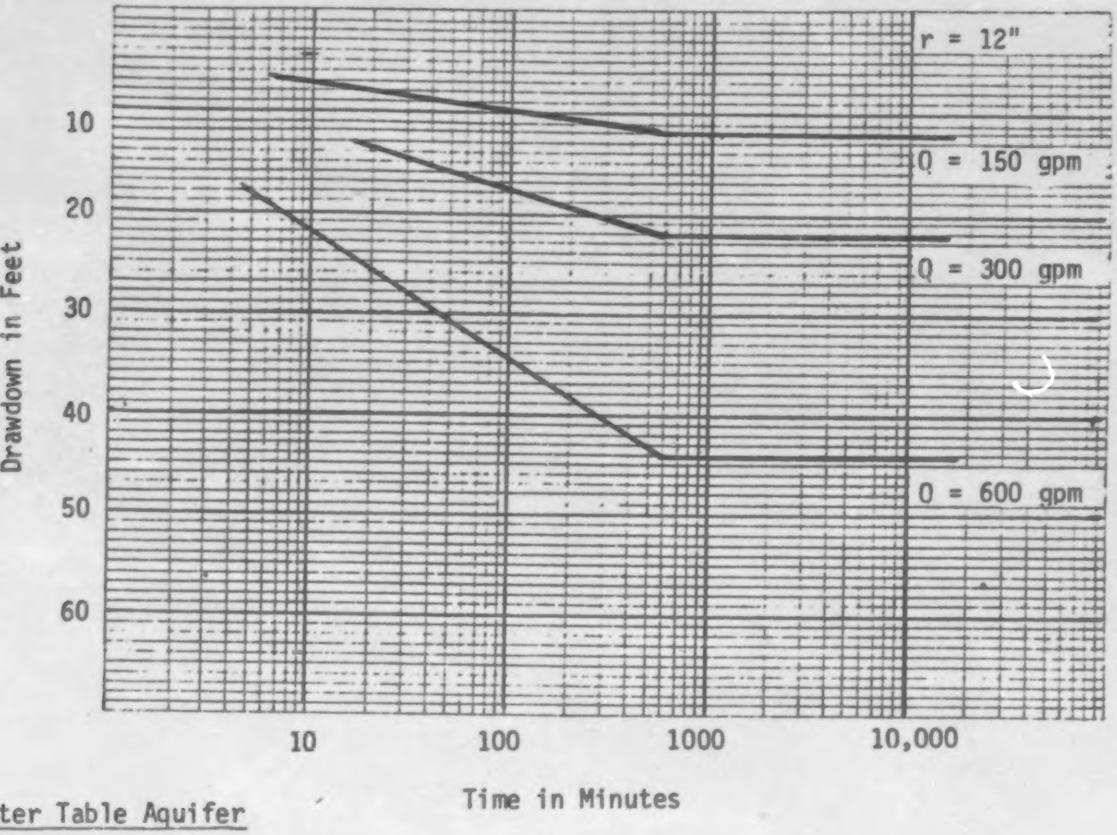
s = Doubles also

s = Change in drawdown over 1 log cycle

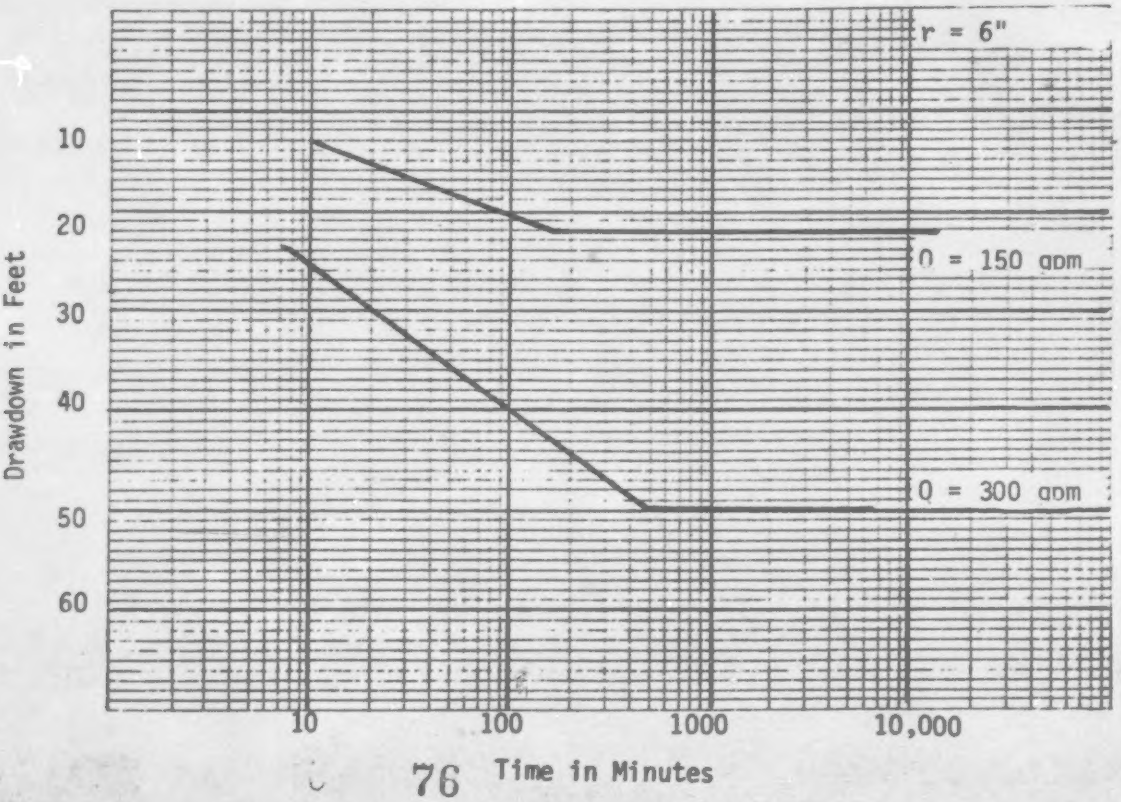


If, however, the aquifer does receive recharge from other aquifers, the cone of depression will approach stability. If recharge equals discharge and no more water is removed from storage, drawdown ceases to increase. This is diagrammed by the following graphs.

Artesian Aquifer

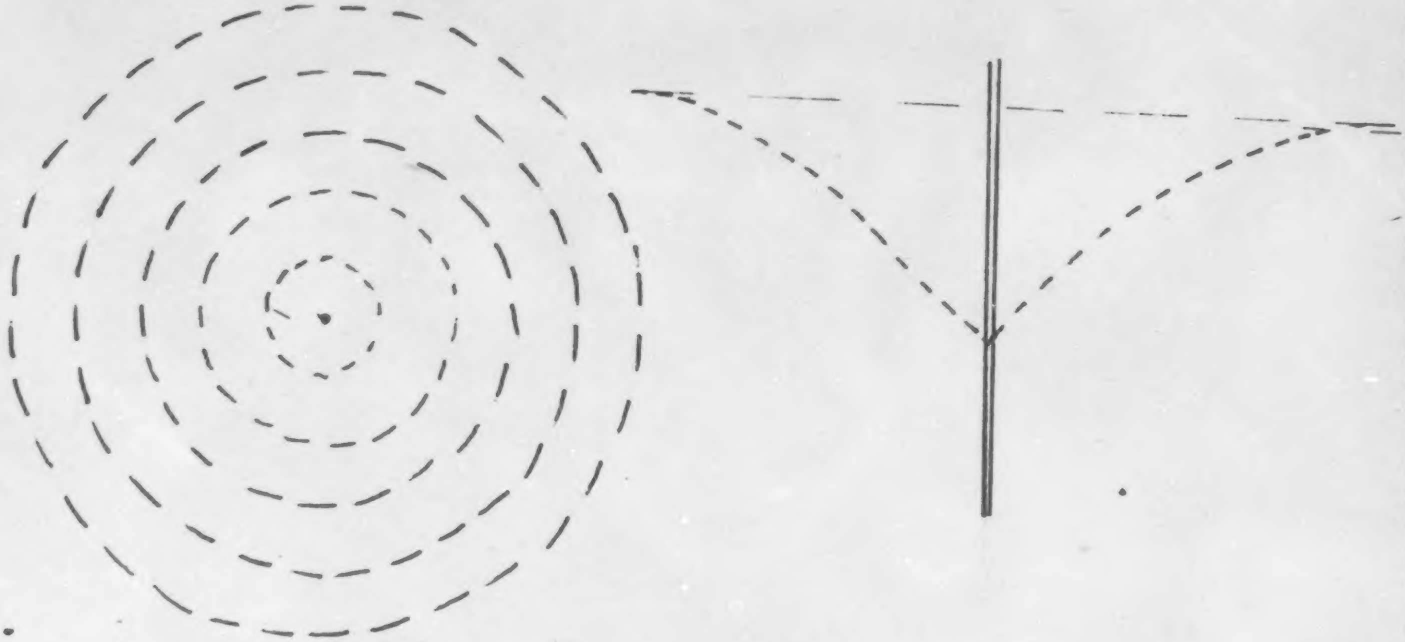


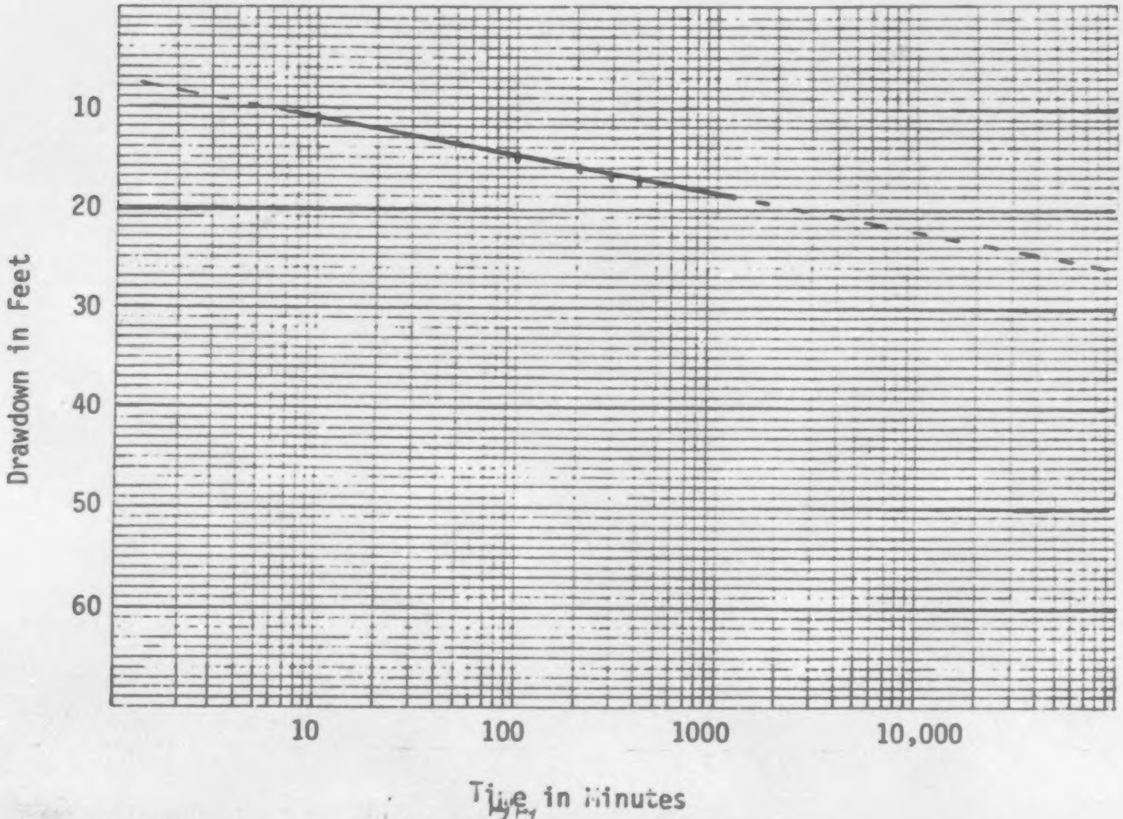
Water Table Aquifer



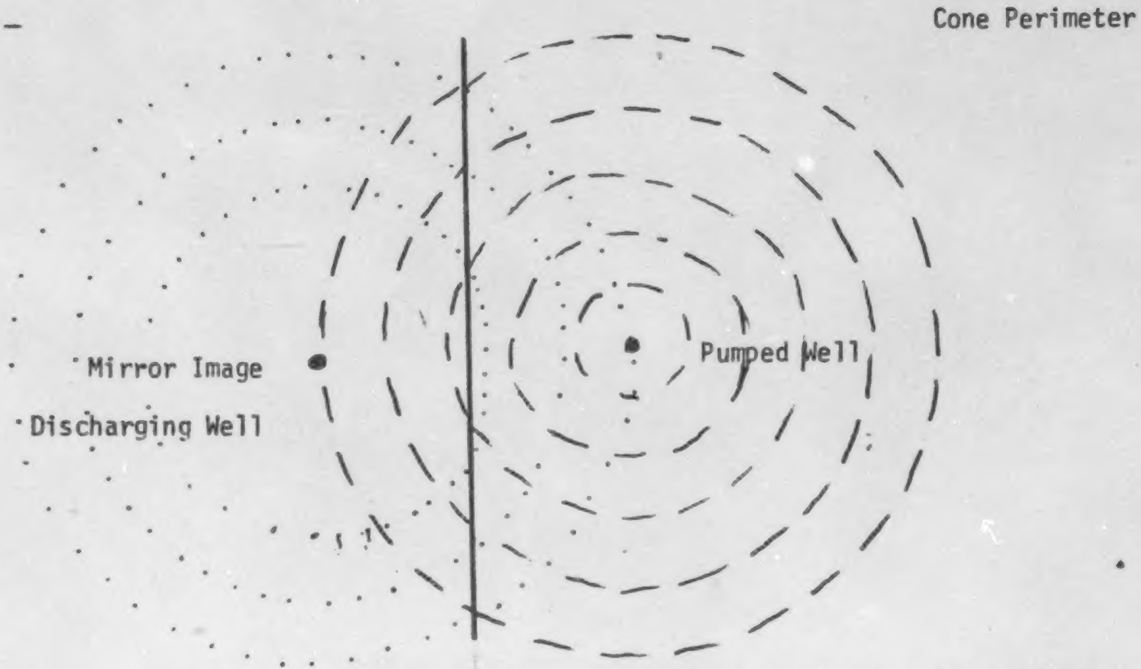
Time Drawdown and Effect of Boundaries

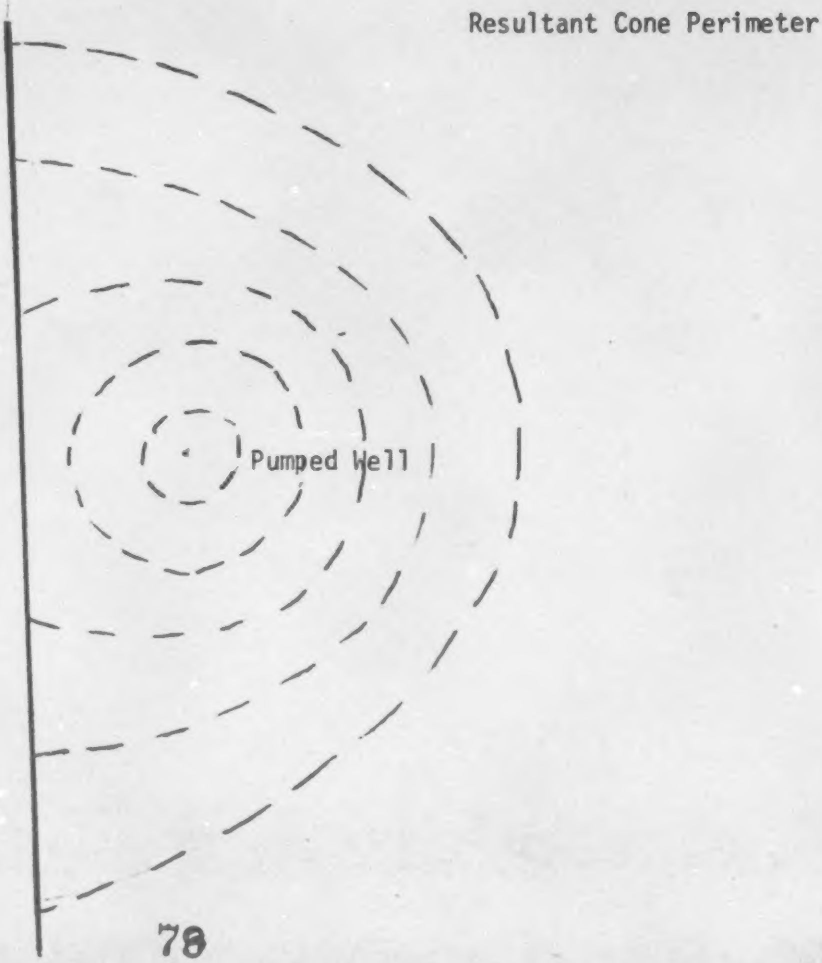
Continuous Aquifer

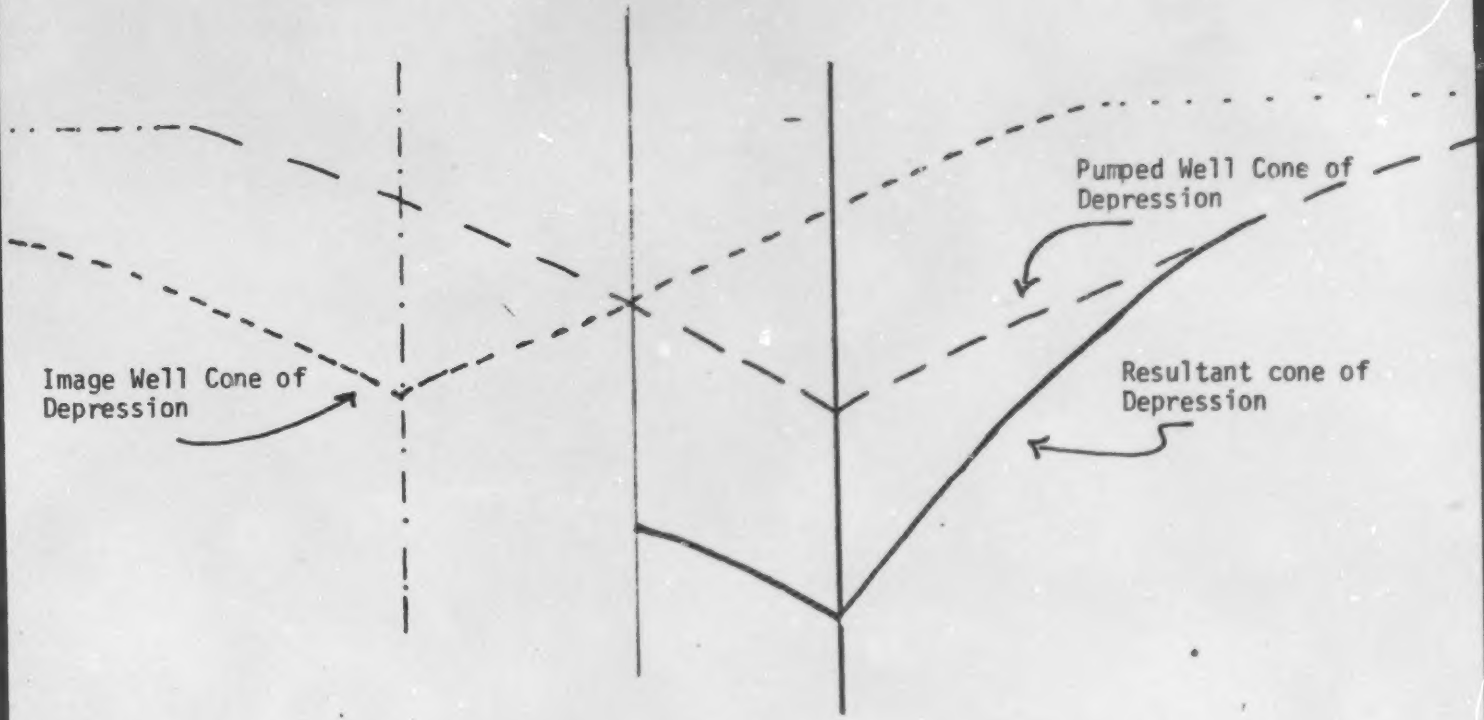


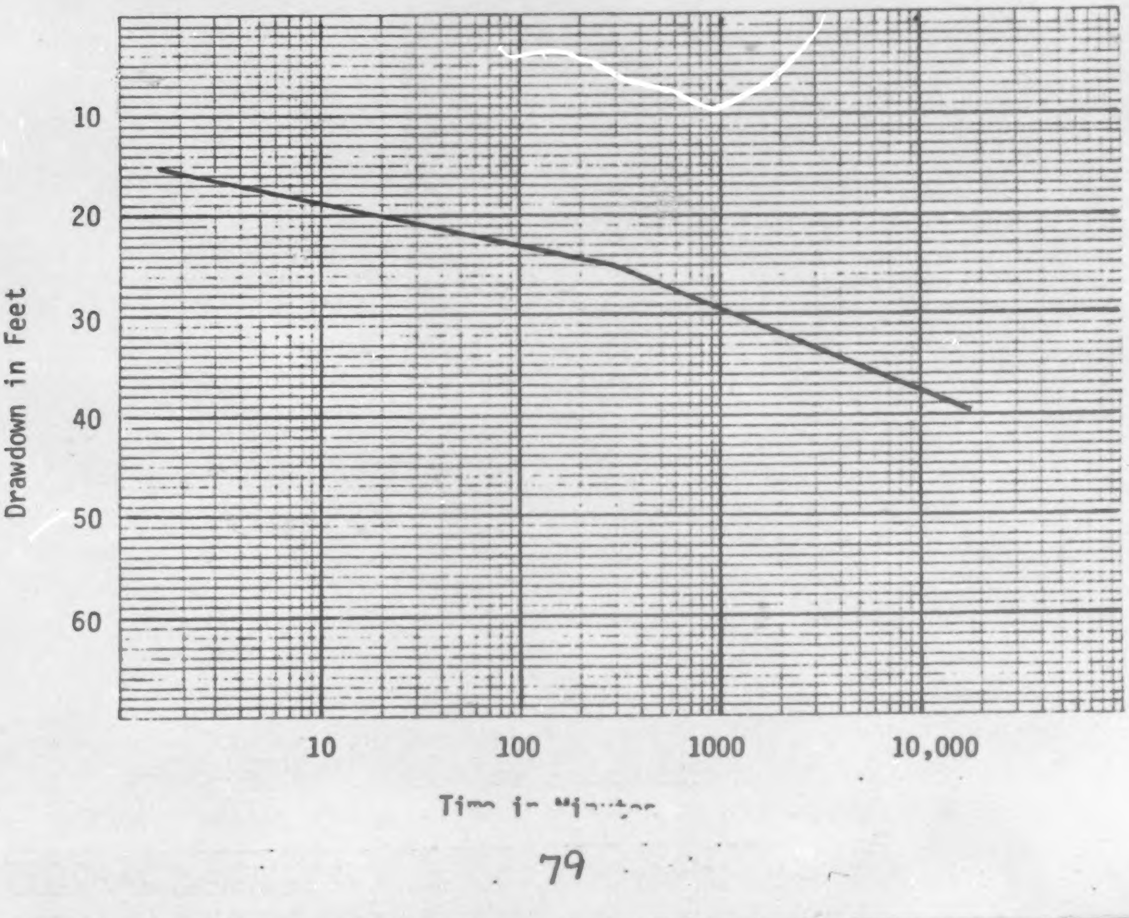


Negative Boundary

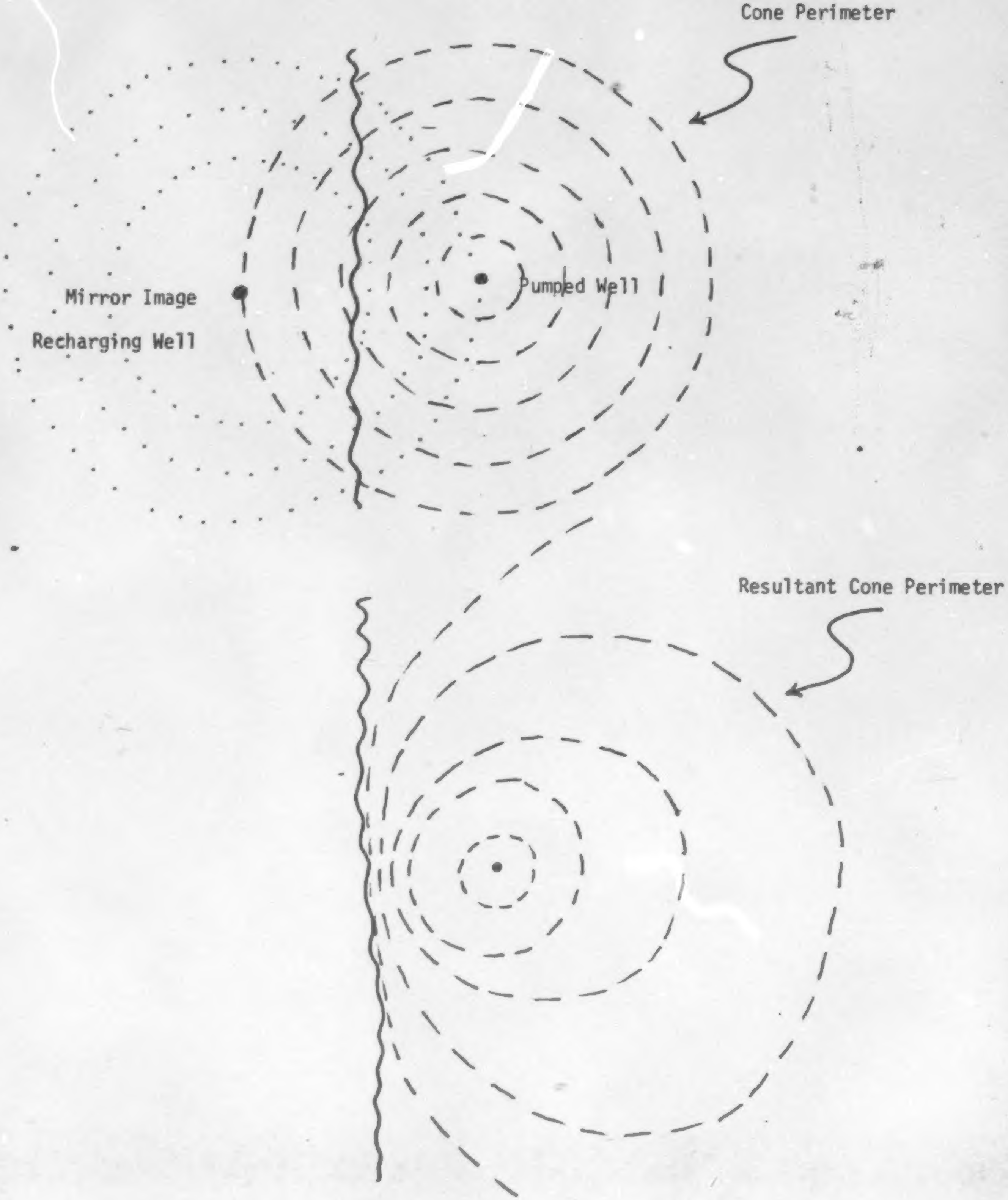

Cone Perimeter
Mirror Image
Discharging Well
Pumped Well


Resultant Cone Perimeter
Pumped Well


Pumped Well Cone of Depression
Image Well Cone of Depression
Resultant cone of Depression


Drawdown in Feet
10
20
30
40
50
60
10
100
1000
10,000
Time in Minutes

Positive Boundary


Cone Perimeter
Mirror Image
Recharging Well
Pumped Well
Resultant Cone Perimeter

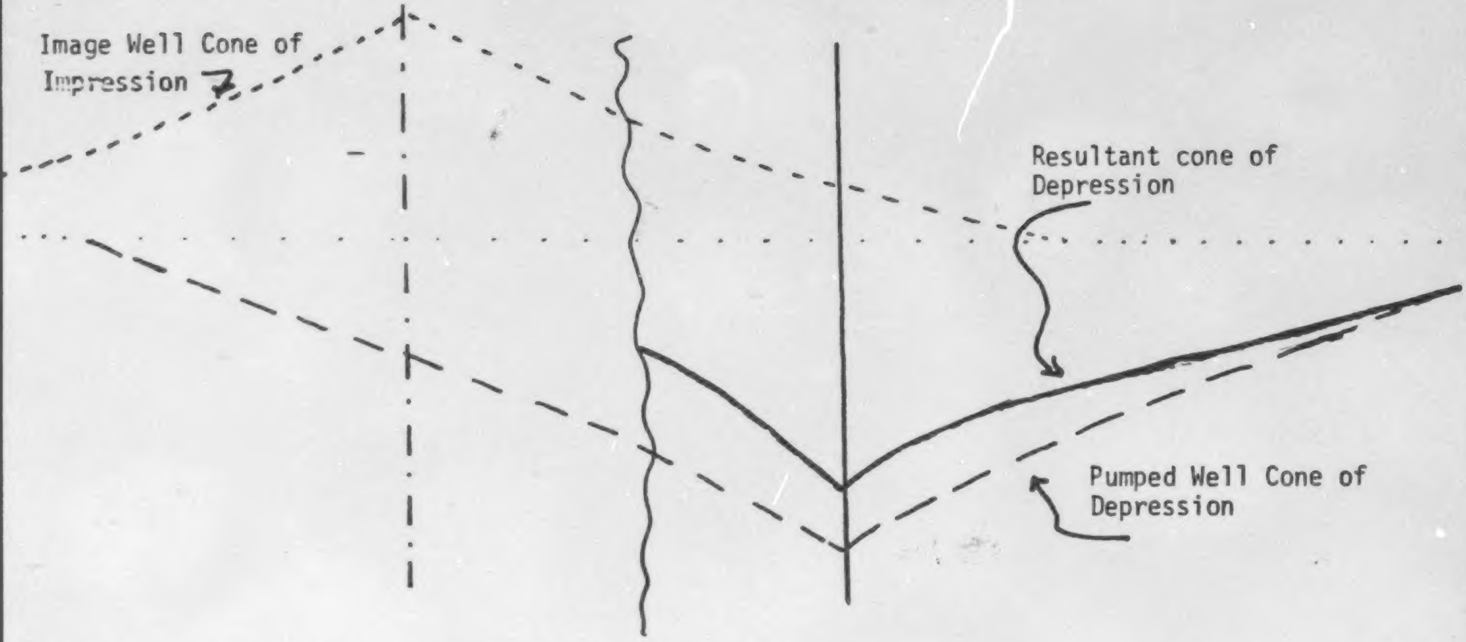
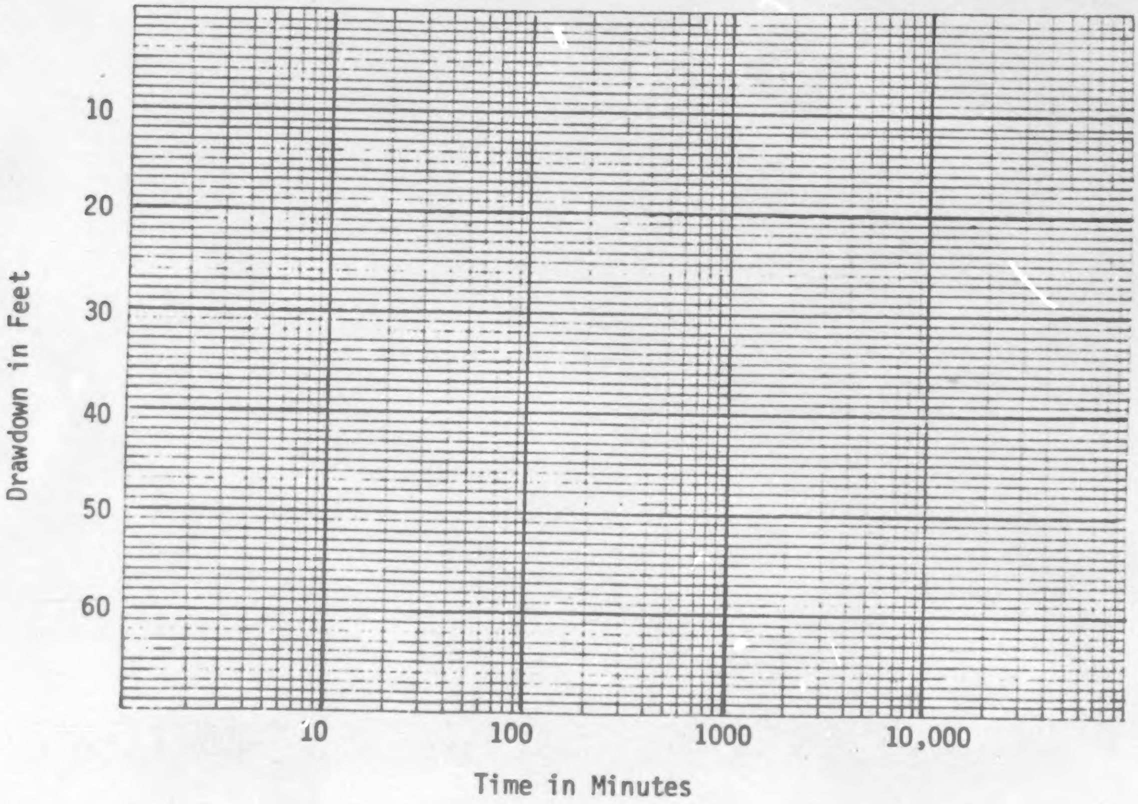


Image Well Cone of Impression
Resultant cone of Depression
Pumped Well Cone of Depression


10
20
30
40
50
60
Drawdown in Feet
10
100
1000
10,000
Time in Minutes

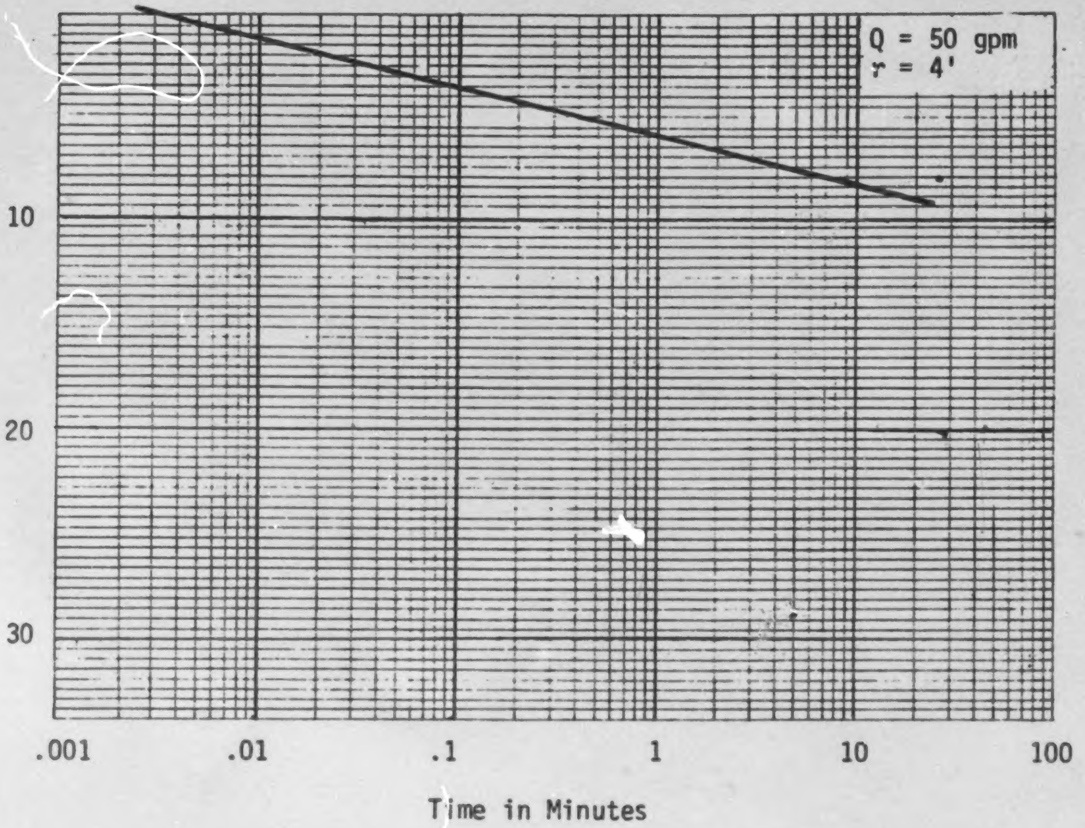
Use of Time-Drawdown to Calculate:

1. Transmissibility (gpd/ft. drawdown)

$$T = \frac{264Q}{\Delta s}$$

2. Storage Coefficient (dimentionless)

$$S = \frac{0.3T\ to}{r^2}$$



Q = Pumping rate (yield) in gpm

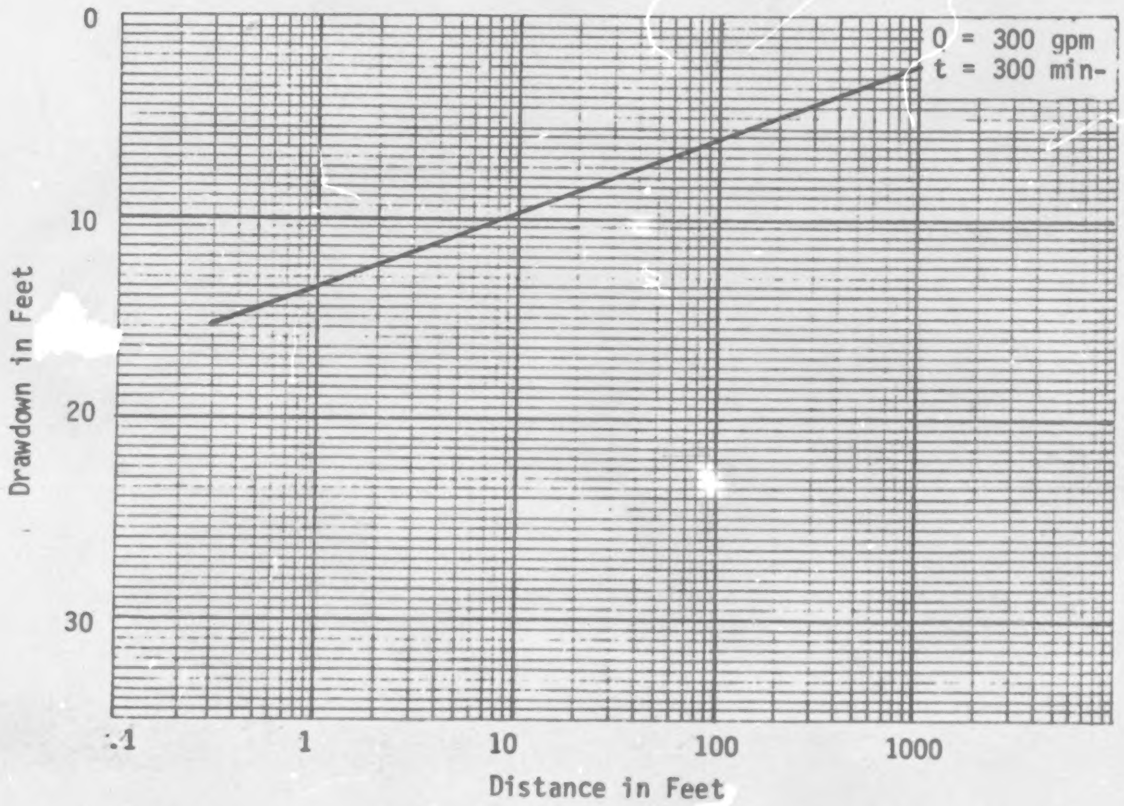
s = Change in drawdown over 1 log cycle

to = Maximum pumping time yielding zero drawdown (expressed in days)

r = Distance from point of measurement to center of pumped well (radius) in feet

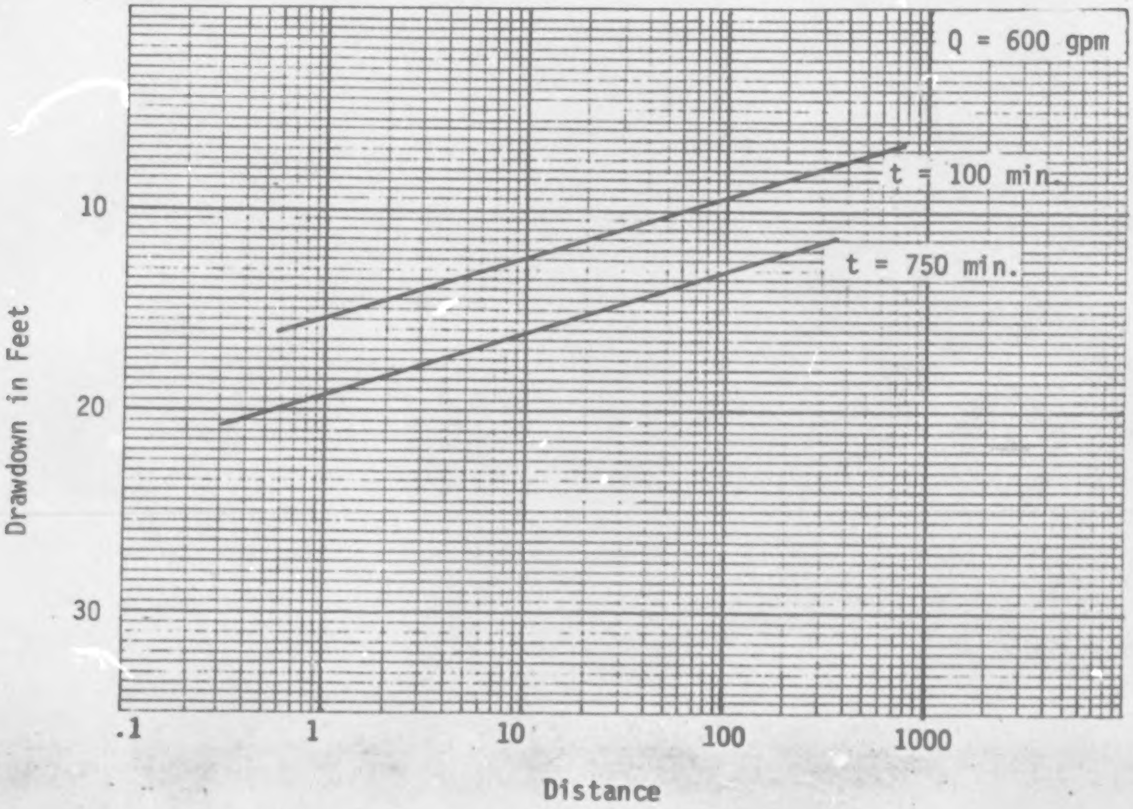
Distance and Drawdown

Drawdown with respect to distance from the center of the pumped well is determined through the use of observation wells. As the cone of depression interceps an observation well, the water level in it drops. This drop in the water level in the observation well will mimic what is actually happening in the aquifer. These measurements are recorded with respect to time. These measurements are then graphed with respect to time and pumping rate.



Distance Drawdown With Respect to Time:

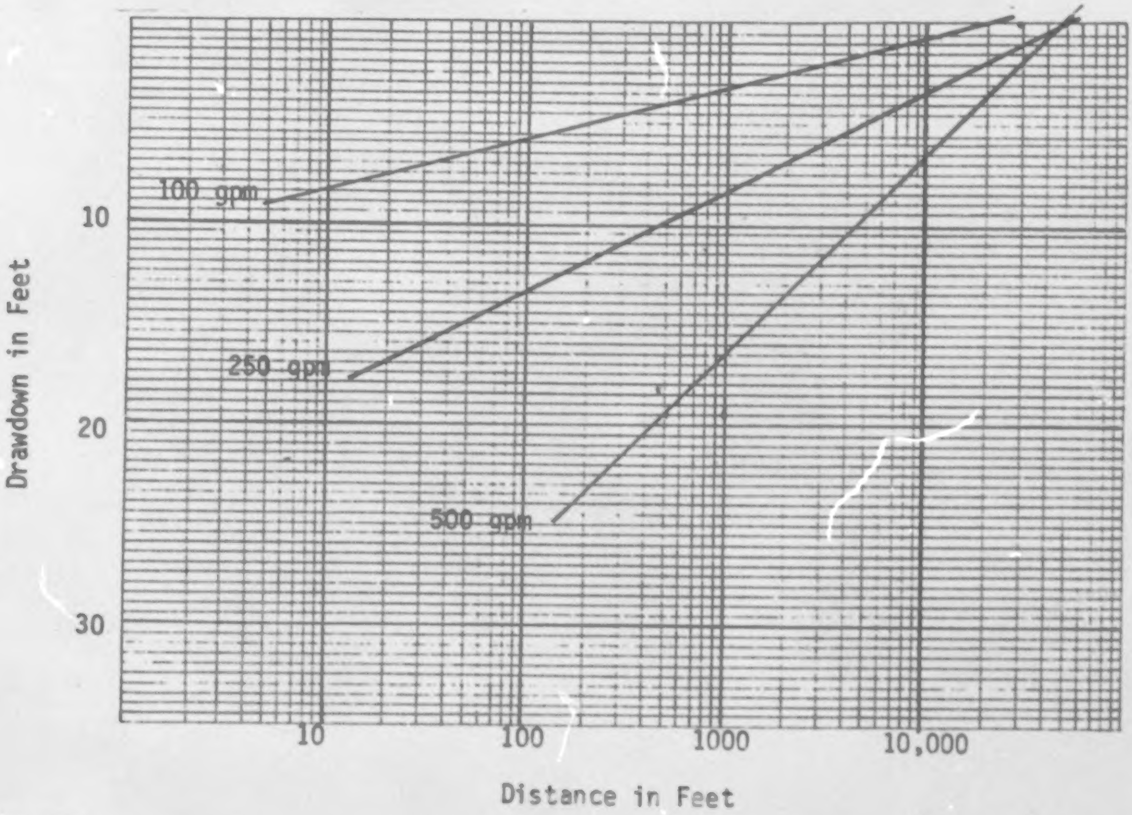
As pumping continues at a constant rate the cone of depression extends to include more area. The rate the cone extends remains constant (in a continuous aquifer) with respect to time. Therefore, the drawdown observed by a series of observation wells correspondingly increases with respect to time until the cone stabilizes.



Distance Drawdown with respect to Pumping Rate

Pumping Rate	Drawdown at x distance from well		
	500'	1000'	5000'
100 gpm	4'	3.2	1.5'
250 gpm	9.7'	8.5	5'
500 gpm	19.5'	16.5	9.5'

For this example time t = 100 min. since pumping began.



Note:

1. Slope = change in drawdown over 1 log cycle.
2. Change in slope is directly proportional to change in pumping rate.
3. Change in drawdown with respect to time proportional to change in pumping rate.

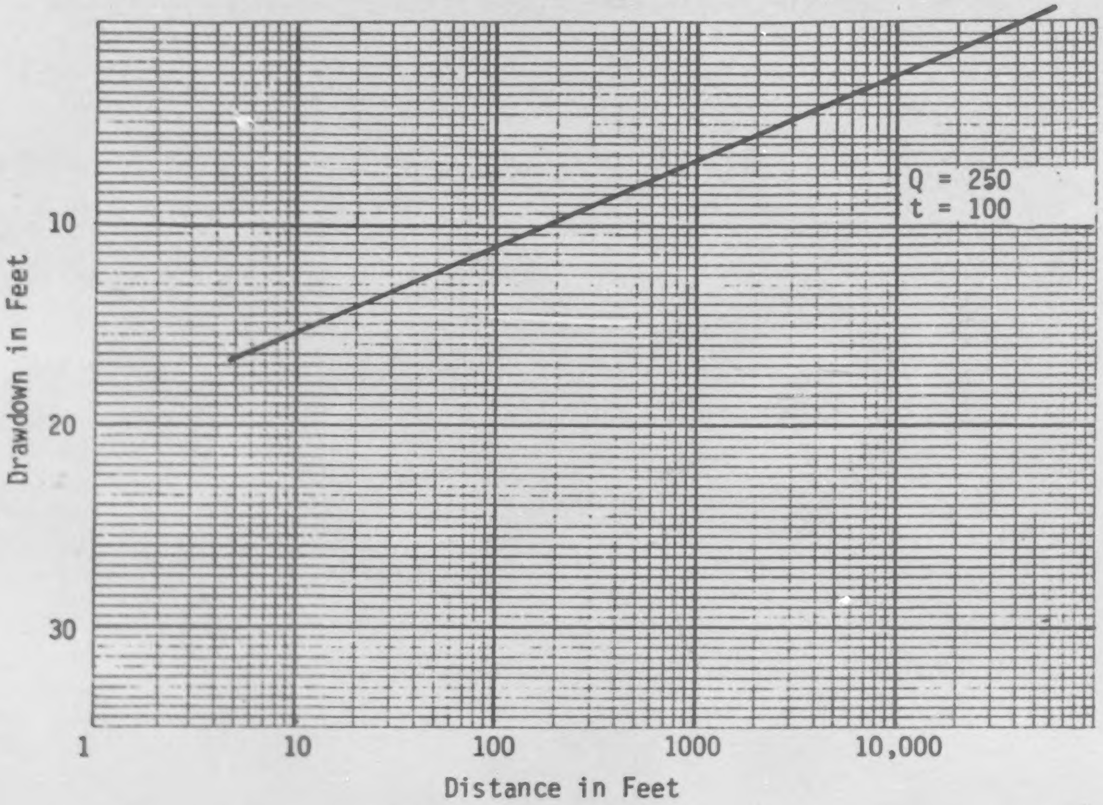
Use of Distance Drawdown to Calculate:

1. Transmissibility (gpd/ft. of drawdown)

$$T = \frac{528\ Q}{\Delta s}$$

2. Storage Coefficient (dimentionless)

$$S = \frac{0.3T\ t}{ro^2}$$



Q = Pumping rate in gpm

s = Change in drawdown over 1 log cycle

t = Time since pumping began at which measurements were taken in days

ro = Distance from center of pumped well at which no drawdown is observed in feet

Distance Drawdown and Well Efficiency

Pumping data

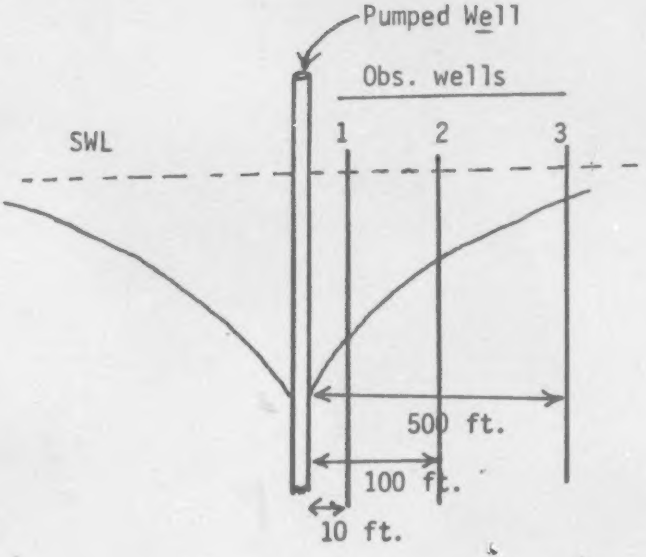
Time (t) = 500 Min.
Rate (q) = 300 gpm
Well diameter = 24"

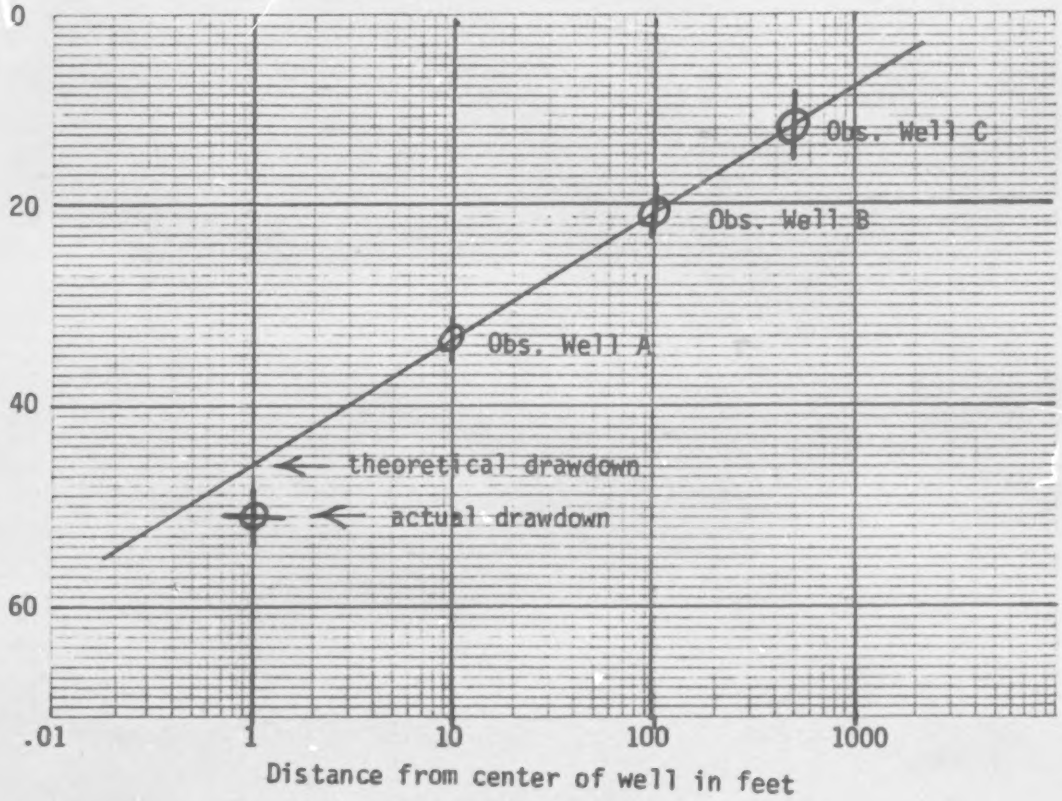
Measured Drawdowns (s)

Pumped well = 51 ft.
Obs. well #1 = 33.5 ft.
Obs. well #2 = 20.5 ft.
Obs. well #3 = 11.0 ft.

Well Efficiency

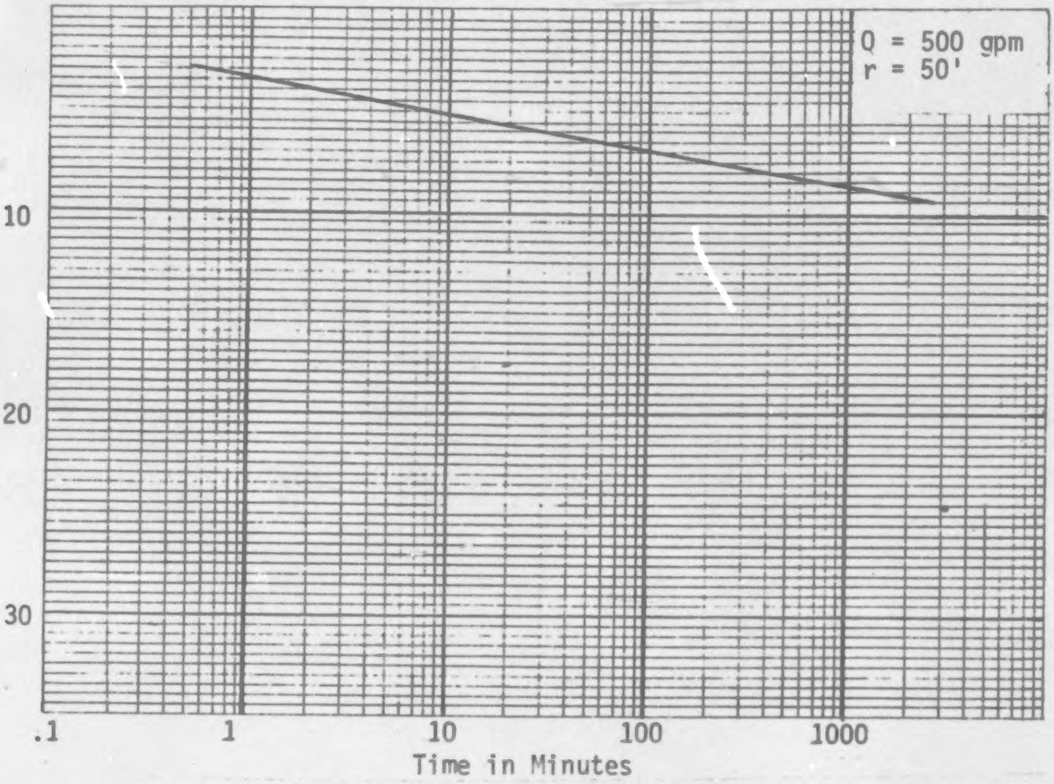
$$= \frac{\text{theoretical drawdown}}{\text{actual drawdown}}$$

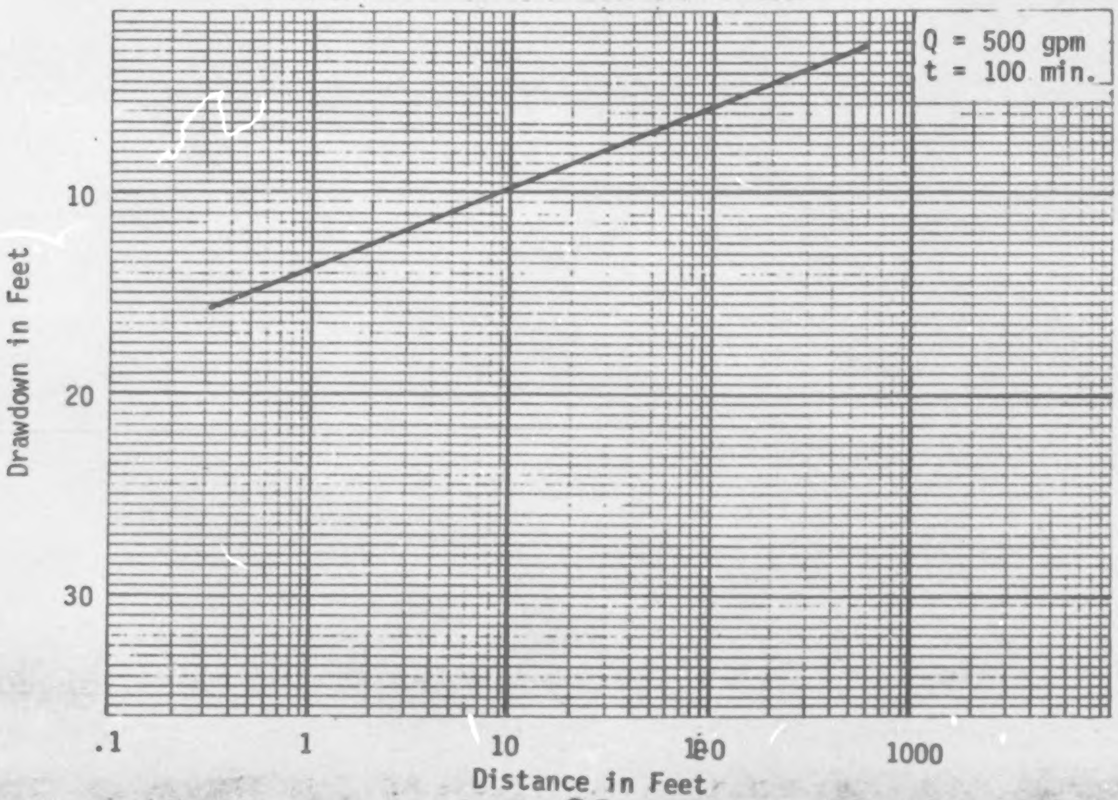

Pumped Well
Obs. wells
1
2
3
SWL
500 ft.
100 ft.
10 ft.



Construction of a Distance-Drawdown Graph From a Time-Drawdown Graph

If only one observation well is available, a distance-drawdown plot can still be made. This is done by converting time drawdown plot at that observation well.

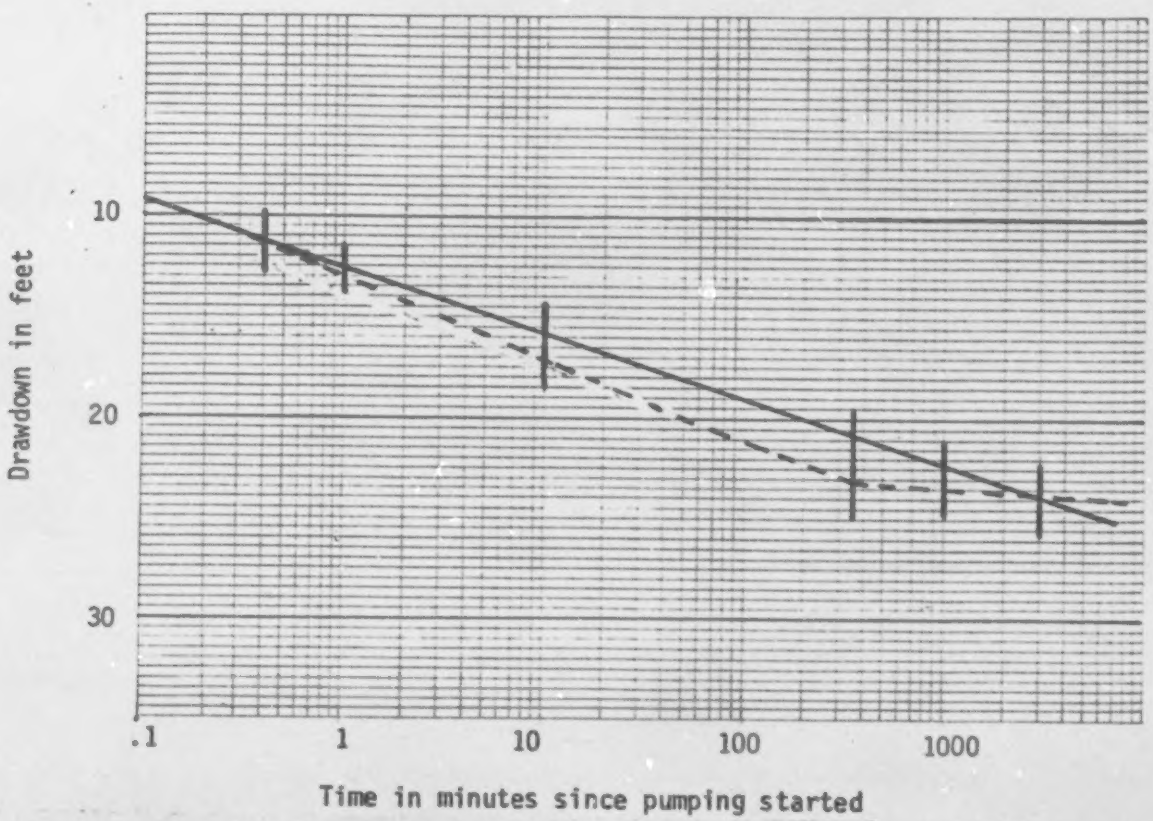




Accuracy in Plotting

In order for any plotted data to be meaningful, accurate original data must be available. An example of how sloppy measurements can affect this curve plot is shown below:

TIME		DRAWDOWN	
Actual	Recorded	Actual	Recorded
.4 Min.	.4 Min.	11.5'	11.5'
1 Min.	1 Min.	12.5'	13'
11 Min.	10 Min.	17'	17'
350 Min.	350 Min.	20'	23'
1000 Min.	1000 Min.	22.5'	23'
3000 Min.	3000 Min.	24'	24'



Practice Problem

Given: (1) Distance to observation wells

Obs. well A = 18'

Obs. well B = 50'

Obs. well C = 200'

(2) Static water level = 10' below ground level

(3) Pumping rate = 200 gpm

(4) Well measurement at 1 ft. from center of well

(5) Pumping test results (see page 23)

Plot: (1) Time drawdowns for pumped well and all 3 observation wells

(2) Distance drawdowns at time to 25 Min., 75 Min., 250 Min., 500 Min., 1000 Min.

(3) Recovery

(4) Time drawdown at pumping rate of 800 gpm at time t = 250 Min.

(5) Distance drawdown at pumping rate of 800 gpm at time t = 250 Min.

From plots determine:

(1) Transmissibility from both time-drawdown and distance drawdown plots.

(2) Storage coefficient from both time-drawdown and distance drawdown plots.

(3) Well efficiency

Convert: Time drawdown of observation well A to distance drawdown plot for 500 Min. and compare with plotted distance drawdown at 500 Min.

From data at time = 1000 Min. since pumping began:

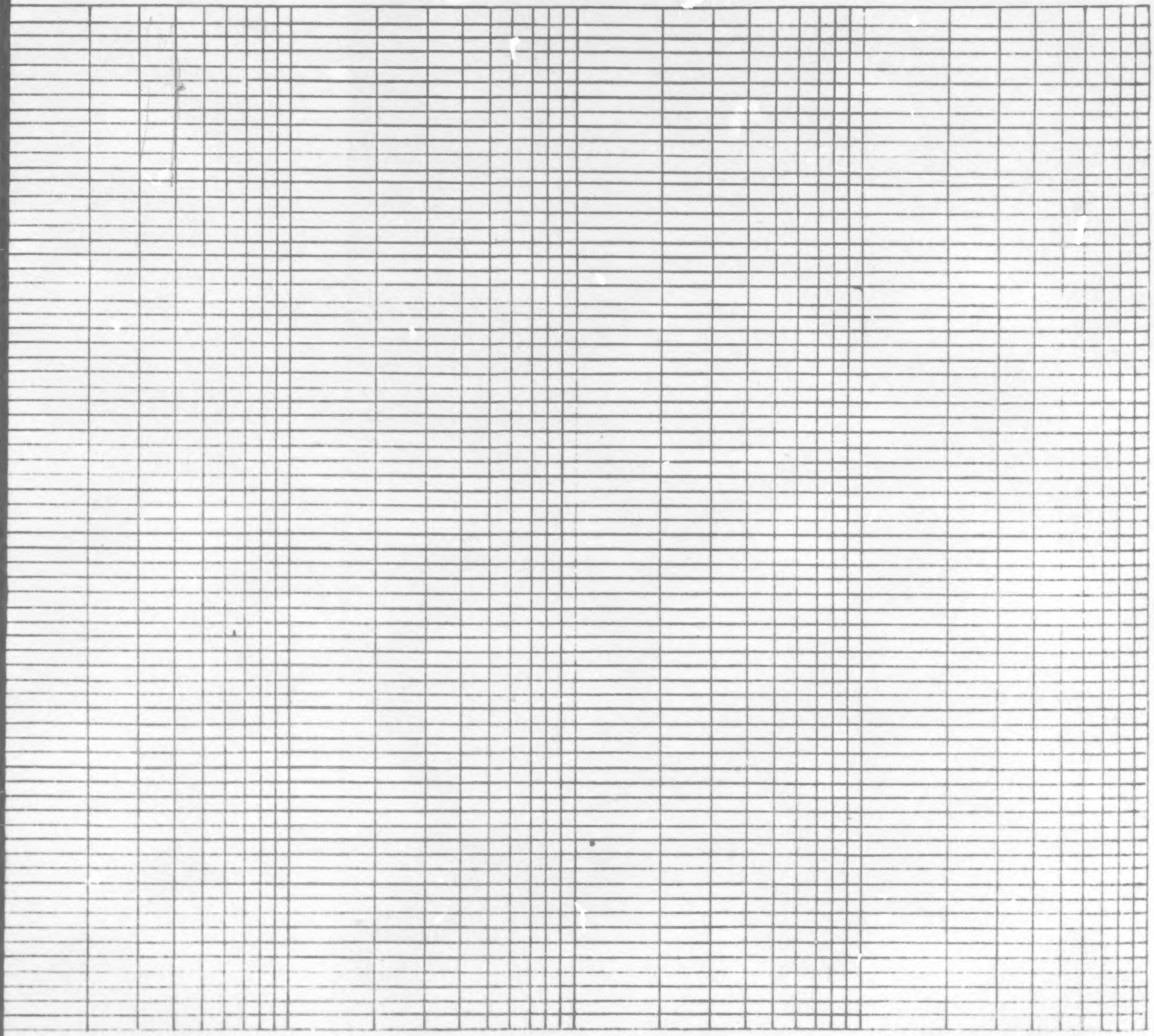
(1) Illustrate the cone of depression.

(2) Use scale ½ inch equals 100 ft.

Time since pumping began in Minutes	Time since pumping ended in Minutes	Depth to Water			
		Pumped Well	Obs. Wells		
			A	B	C
0		10'	10'	10'	10'
2		27'	10'	10'	
5		29'	12'		
7		29.8'			10'
10		30.5'	13'		
25		32.5'	15.2'	11'	10'
50		34.5'	17'	12.5'	
75		35'	18'	13'	10'
100		35.5'	18.5'	14'	
250		37.5'	20.5'	15.3'	10'
500		39'	22'	17.5'	11.5'
750		39.8'	23.5'	18.5'	12.5'
1000	0	40.5'	24'	19'	13.5'
1002	2	33.5'			
1005	5	31.5'			
1007	7	30.7'			
1010	10	30'			
1025	25	28'			
1050	50	26'			
1075	75	25.5'			
1100	100	25'			
1250	250	23'			
1500	500	21.5'			
1750	750	20.7'			
2000	1000	10'			

TIME DRAWDOWNS

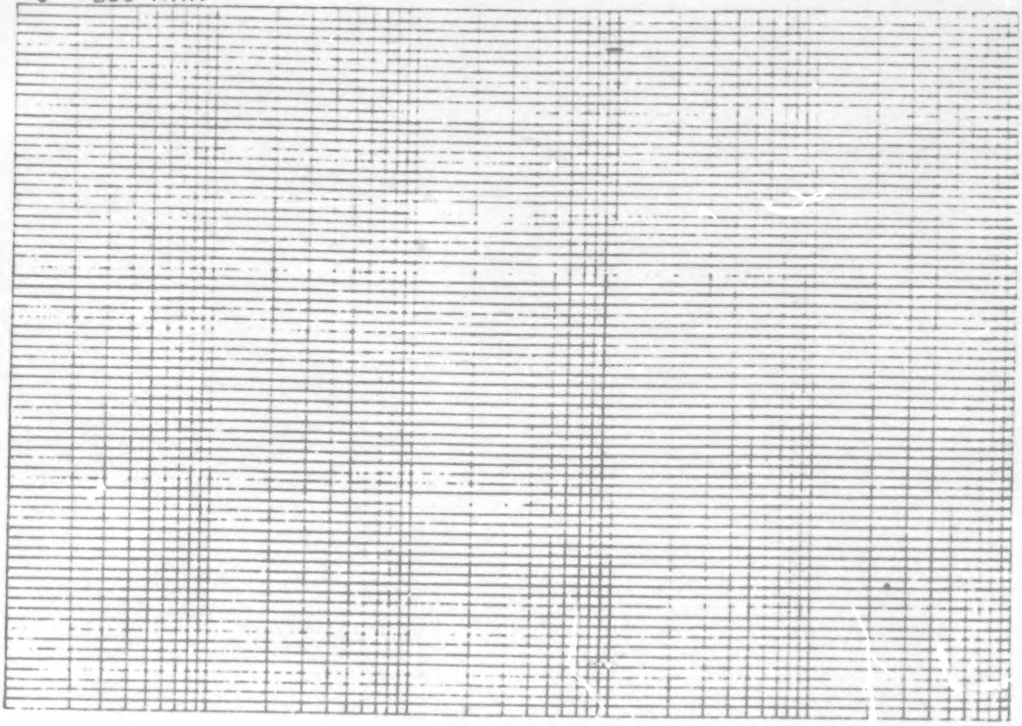
DISTANCE DRAWDOWNS



RECOVERY

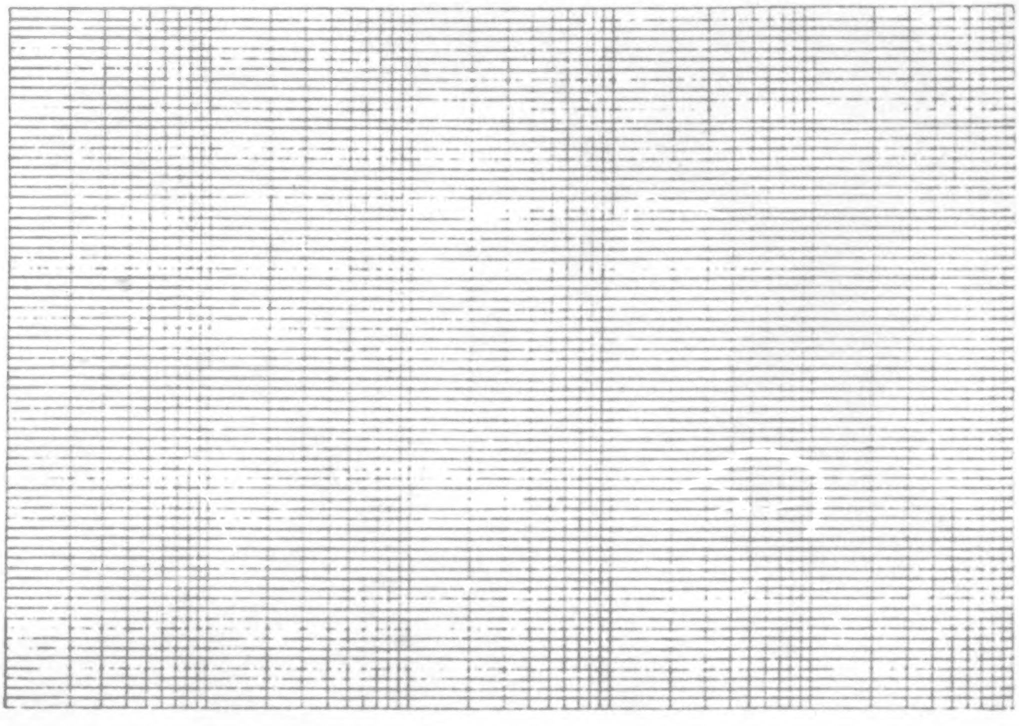
800 GPM Time Drawdown

t = 250 Min.

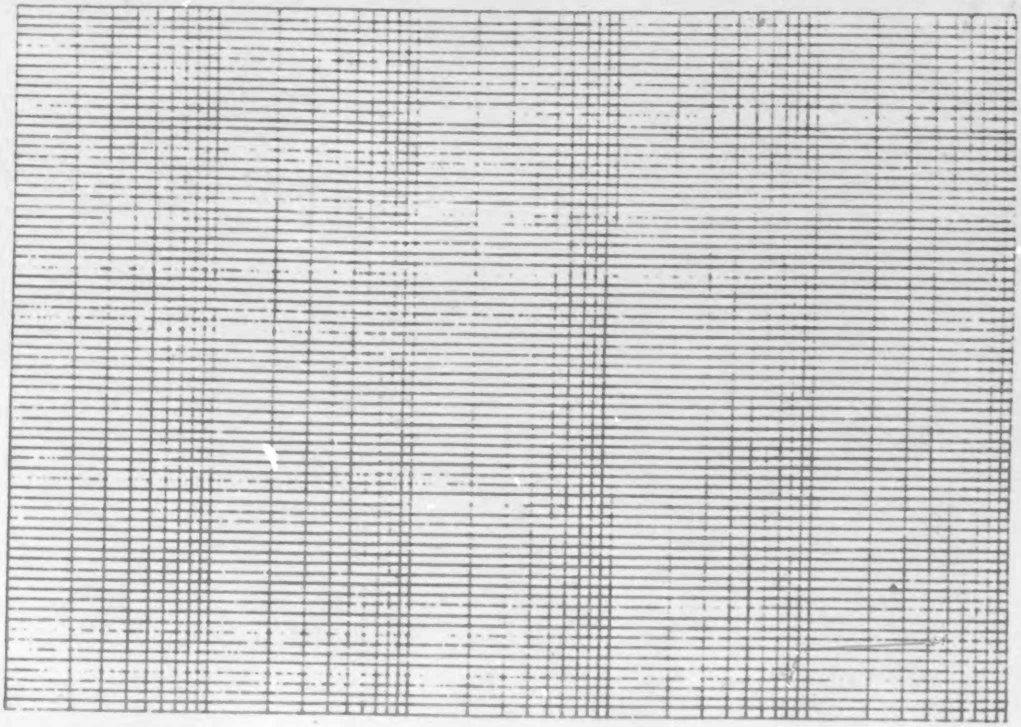


800 GPM Distance Drawdown

t = 250 Min.



Conversion of Time to Distance Charts



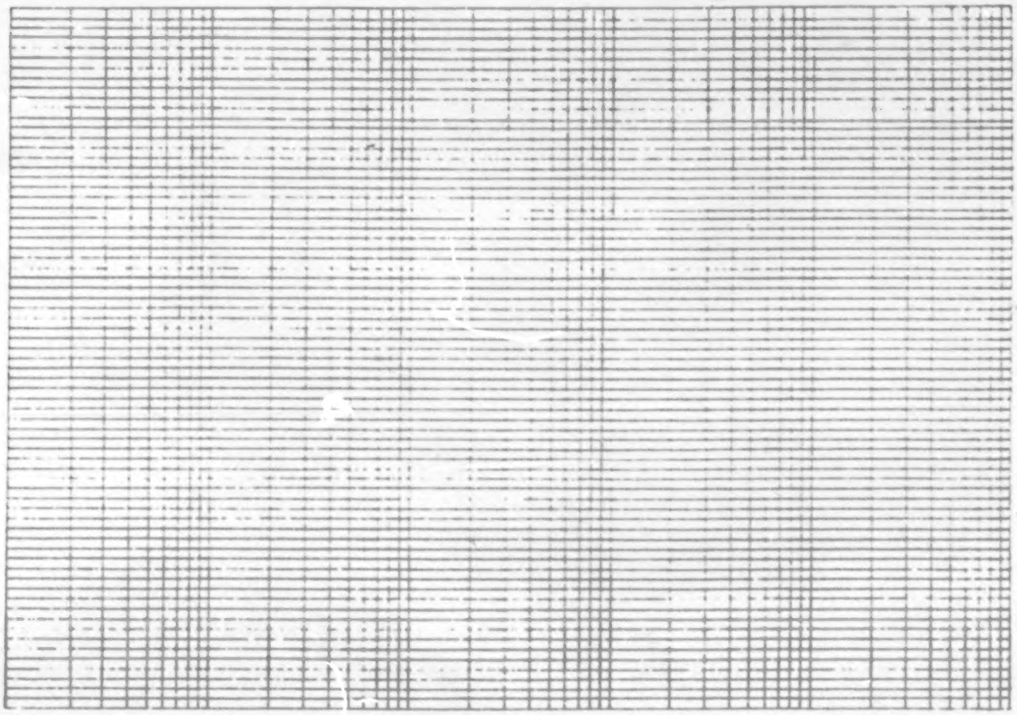


Illustration of Cone of Depression

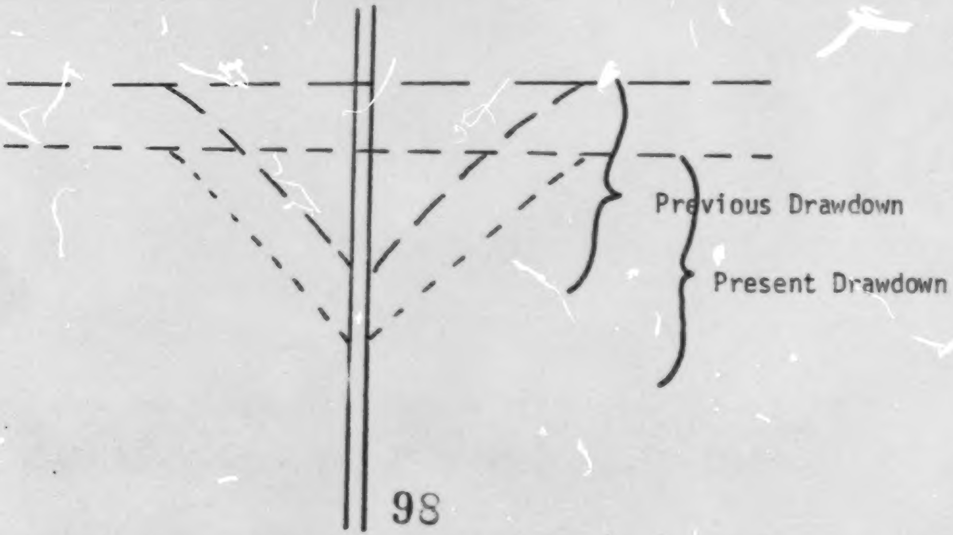
BASIC PROBLEM SOLVING

As with any man made apparatus, problems occur in planning and use of wells and well fields. However, in order to evaluate these problems, well records must be examined. Some situations require careful examination and comparison of past well data where others require extensive testing over a short period of time.

Three examples of problems requiring comparison of old and present records have been examined earlier. These same three conditions are illustrated again. These conditions not only reflect the need for preventative maintenance but also the adequacy of the design for the aquifer. Also from correcting these three problem situations, basic problem solving techniques are illustrated. These techniques can then be used in correcting other problem situations. Examples of these are also included.

Depleting Aquifer

Shows a drop in static water level without appreciable change in drawdown or calculated transmissibility or storage coefficient.



Loss of Pump Efficiency

1972 Measurements

1. Date - August 23, 1972
2. Yield - 240 gallons per minute
   Test Method - Meter (cal. 6-4-72)
3. Static water level = 143'
   Test Method - Air Line
   Time since pumping stopped - 2 hrs.
4. Drawdown
   Test Method - Air line 18" from well center

Time in Minutes	Drawdown in Feet
5	6.5'
10	7.5'
50	11.5'
100	13'
500	16'
1000	17.5'

5. Storage coefficient = 0.22

$$\left(S = \frac{0.3\ T\ to}{r^2}\right)$$

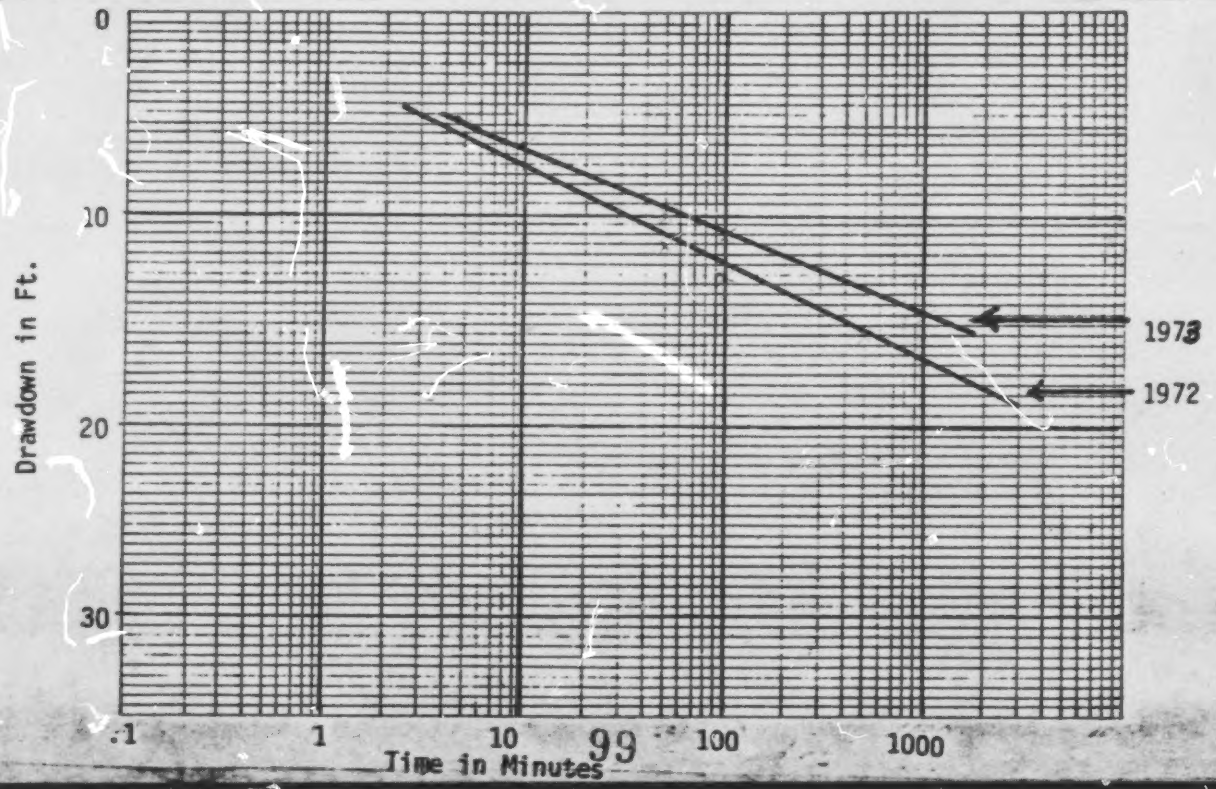
1973 Measurements

1. Date - August 10, 1973
2. Yield - 210 gallons per minute
   Test Method - Meter (cal. 5-30-73)
3. Static water level - 145'
   Test Method - Air Line
   Time since pumping stopped - 2 hrs.
4. Drawdown
   Test Method - Air line 18" from well center

Time in Minutes	Drawdown in Feet
5	5.5'
10	6.5'
50	10'
100	11'
500	14'
1000	15'

5. Storage coefficient = 0.27

$$\left(S = \frac{0.3\ T\ to}{r^2}\right)$$



Incrustation

1968 Measurements

1. Date - August 14, 1968
2. Yield - 420 gallons per minute
   Test Method - meter (cal. 6-4-68)
3. Static water level - 102'
   Time since pumping stopped - 2 hrs.
4. Drawdown
   Test Method - Air line 18" from well center

Time in Minutes	Drawdown in feet
5	8'
10	10'
100	12.5'
500	14.8'
1000	15.8'

5. Storage coefficient = 0.24

$$\left(S = \frac{0.3\ T\ to}{r^2}\right)$$

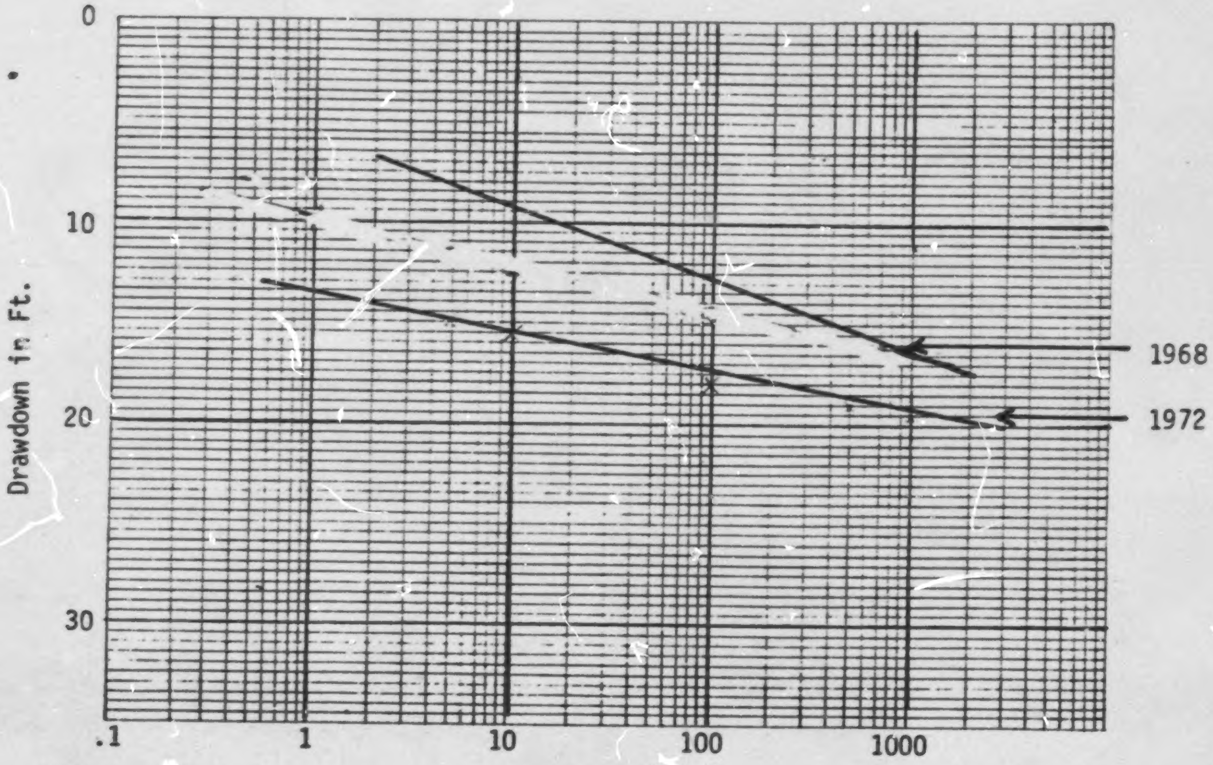
1972 Measurements

1. Date - August 31, 1972
2. Yield - 250 gallons per minute
   Test Method - meter (cal. 6-1-72)
3. Static water level - 102'
   Time since pumping stopped - 2 hrs
4. Drawdown
   Test Method - Air line 18" from well center

Time in Minutes	Drawdown
5	15'
10	15.5'
100	18'
500	19'
1000	19.5'

5. Storage coefficient = 0.00002

$$\left(S = \frac{0.3\ T\ to}{r^2}\right)$$



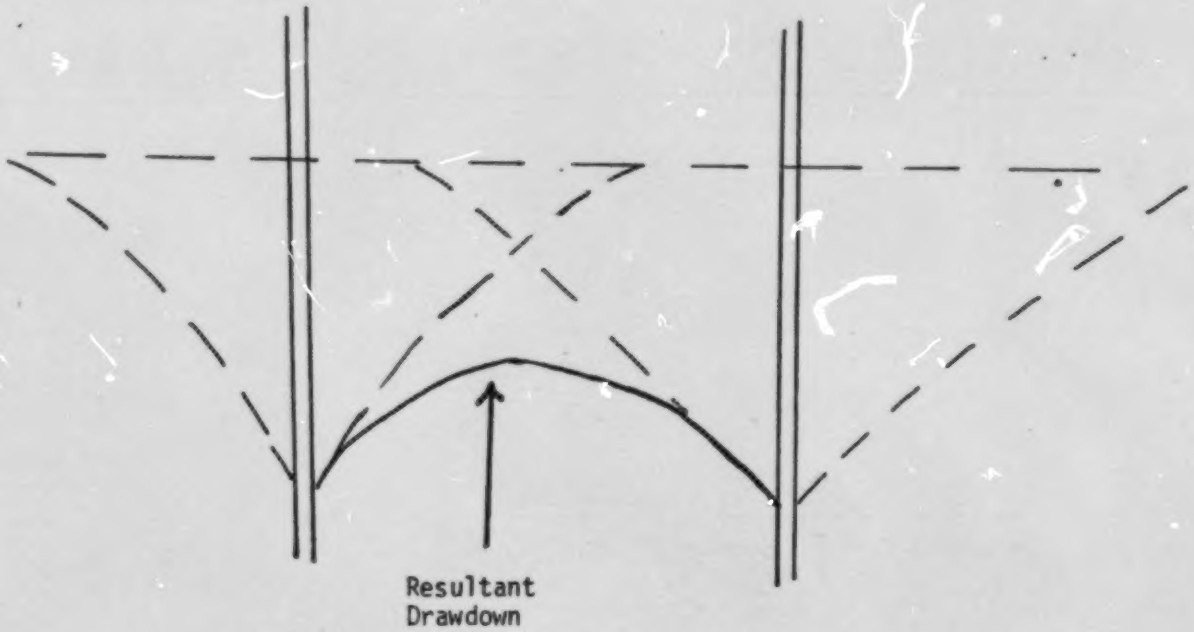
In looking at techniques which can minimize these problems we see two things reoccuring--changing pumping rate and reducing pumping time.

In a depleting aquifer, reducing the pumping rate to correspond to the available drawdown corrects the loss of well efficiency. Remember, reducing the pumping rate proportionatly reduces the drawdown. Remember, no more than 70% of the available should be used.

With a loss of pump efficiency, one should examine the rate and cause of the wear on the pump. Perhaps this situation causing this problem may be corrected by:

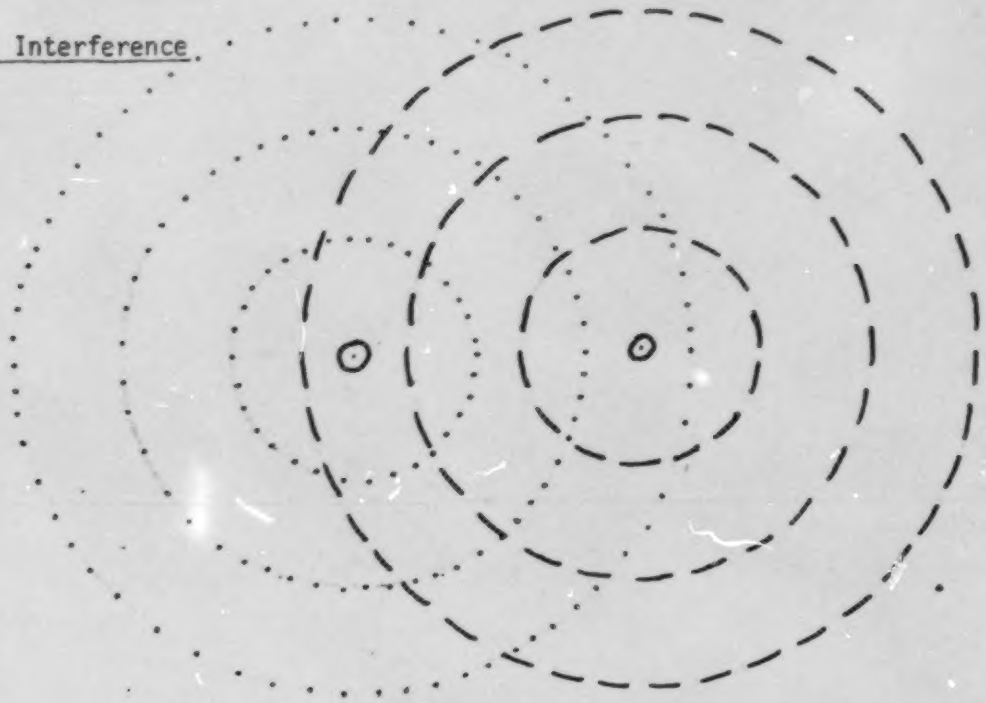
1. Lowering the pumping rate. The pump must work longer to move an equal amount of water but drawdown is less and therefore the work done by the pump is less.

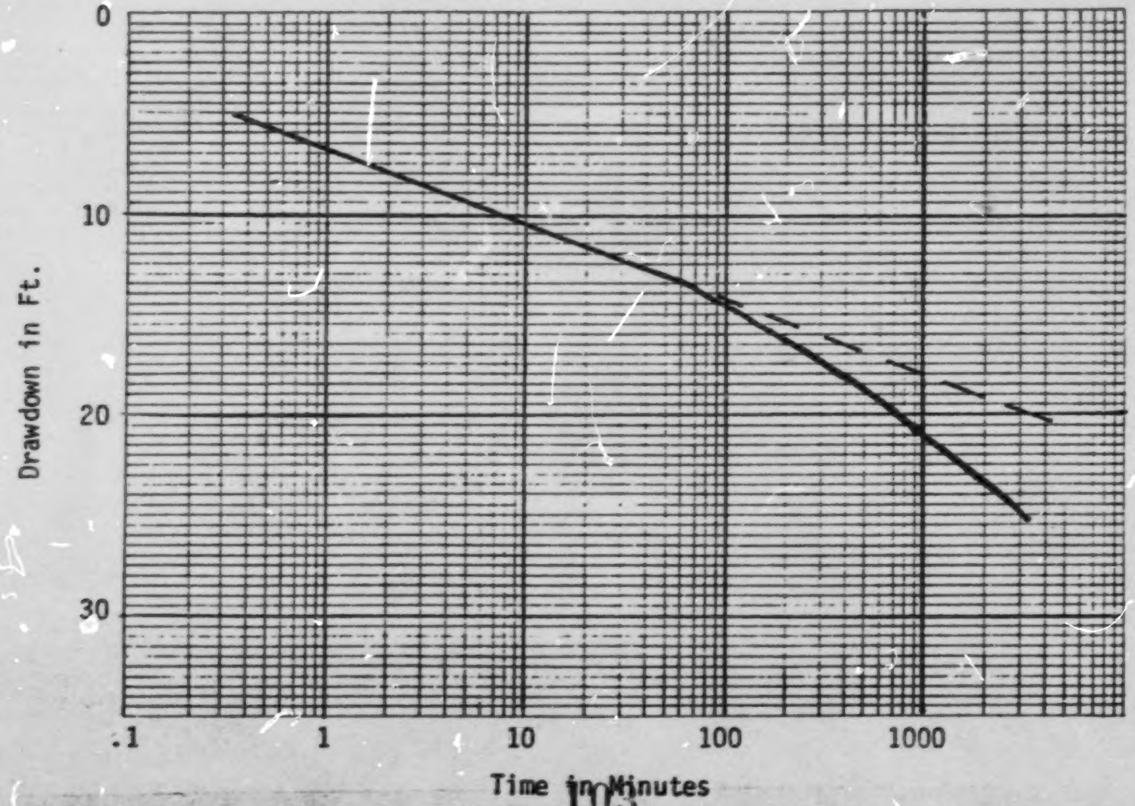
2. Increasing the pumping rate to more efficiently use the available drawdown. (This may require re-locating the pump to accommodate this increased drawdown.) This results in shorter intervals of pumping time.
3. Splitting the pumping load between two or more wells. Here well interference must be taken into consideration.



Where incrustation is the problem, lowering the pumping rate will improve the situation. Note that drawdown is directly proportional to pumping rate. Therefore, lowering the pumping rate decreases the drawdown which requires less of a hydraulic gradient to move the necessary amount of water and yields a reduced entrance velocity. Remember, a decrease in entrance velocity decreases the rate of incrustation.

Well Interference





If a problem is created by this well interference, alternative pumping and design must be examined. Four of these alternatives are:

1. Decrease pumping time

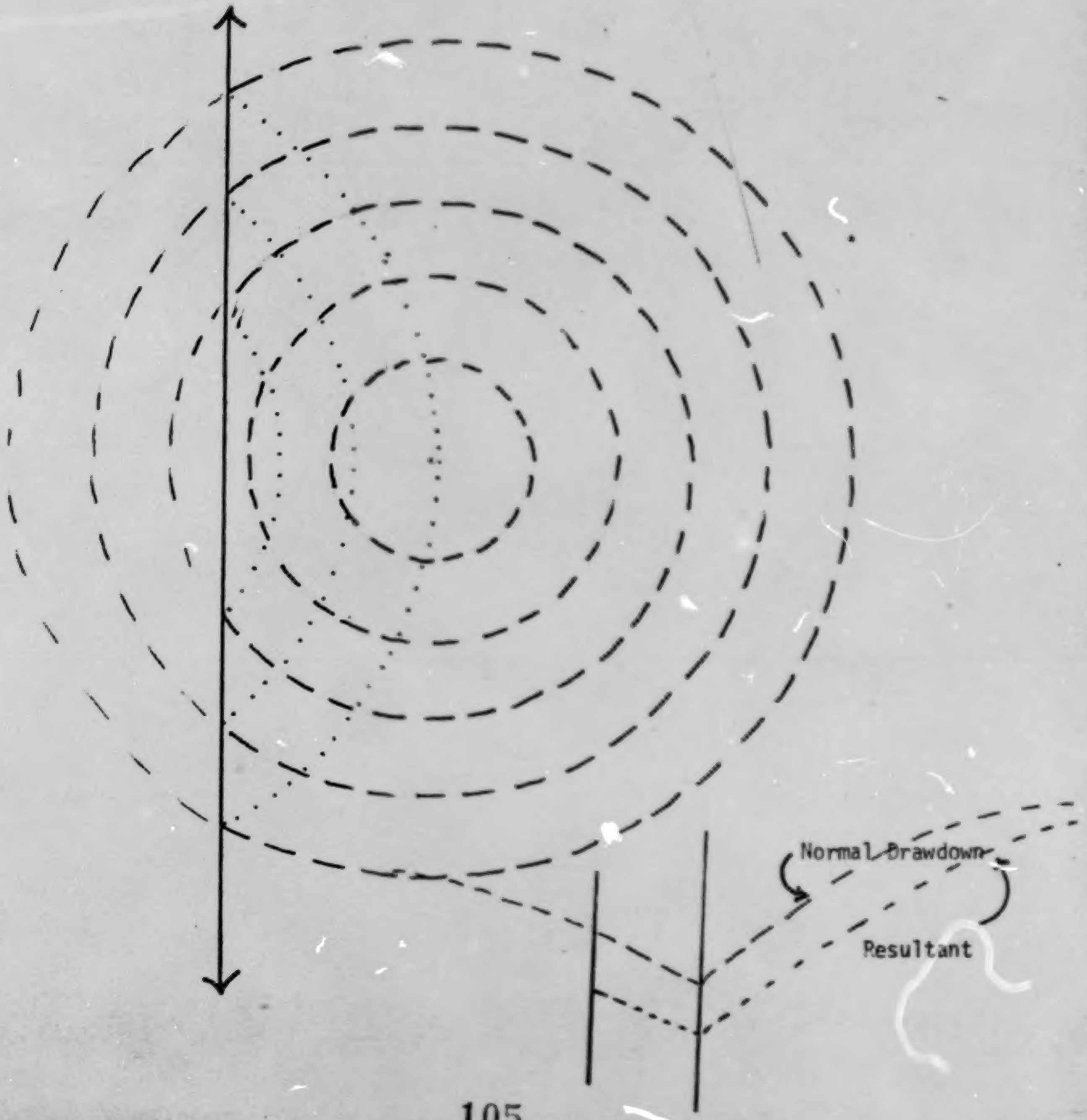
2. Decrease pumping time with an increase in pumping rate.

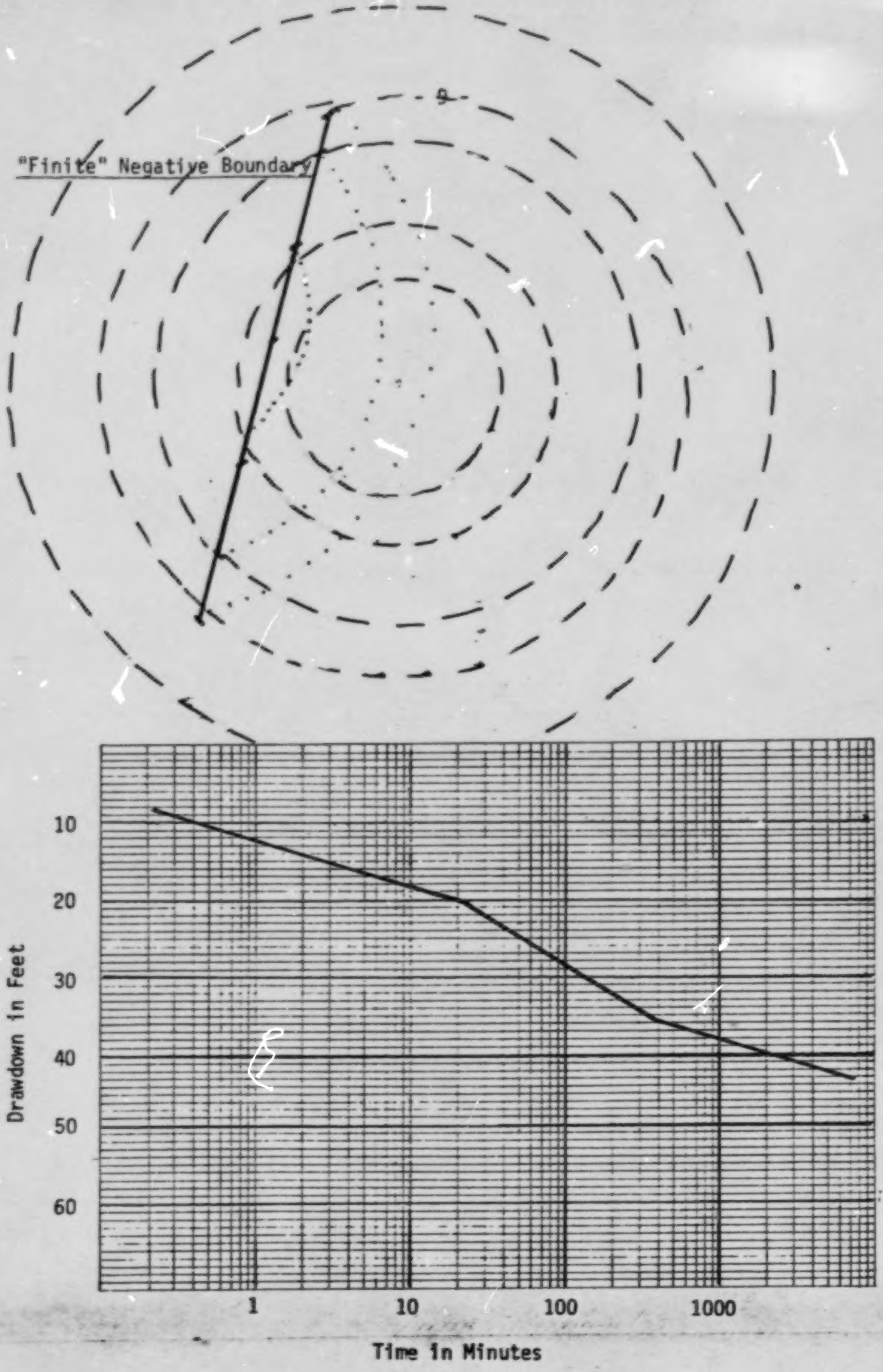
3. Pump wells alternately.

4. Use different aquifers.

Infinite Length Neg. Boundary

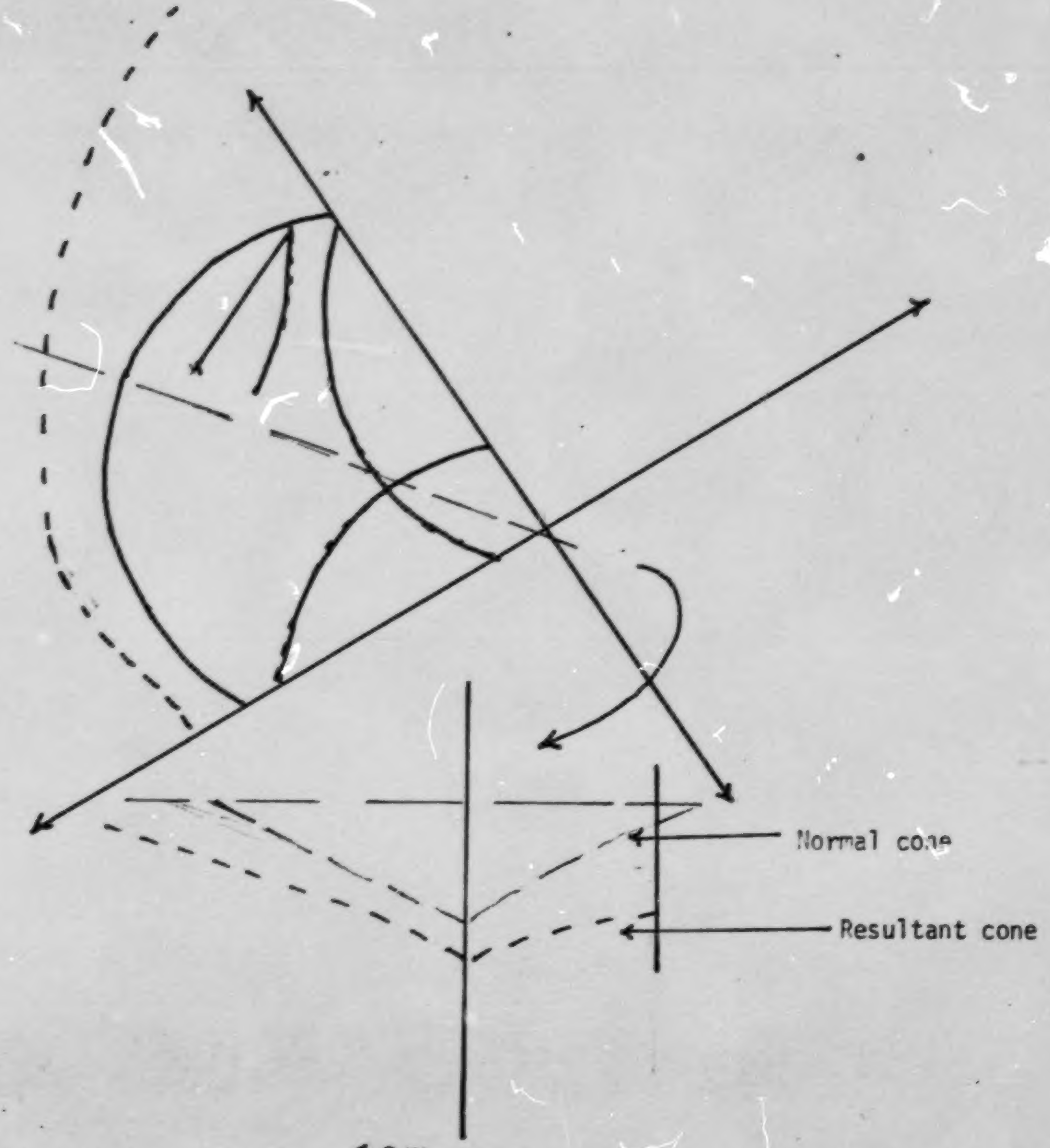
Shows effect similar to well interference and similar corrective measures can be used. Also one may consider abandoning and redrilling farther from boundary.


Normal Drawdown
Resultant


"Finite" Negative Boundary
Drawdown in Feet
10
20
30
40
50
60
1
10
100
1000
Time in Minutes

With a negative boundary whose extent will be entirely encompassed before stabilization is achieved, the drawdown will return towards the normal. In this case serious thought should be given to accepting the temporary increase in rate of drawdown even though the efficiency of the well is decreased during this time period.

Multiple Negative Boundaries



RECORD FILE, PLANNING AND CONTRACTS

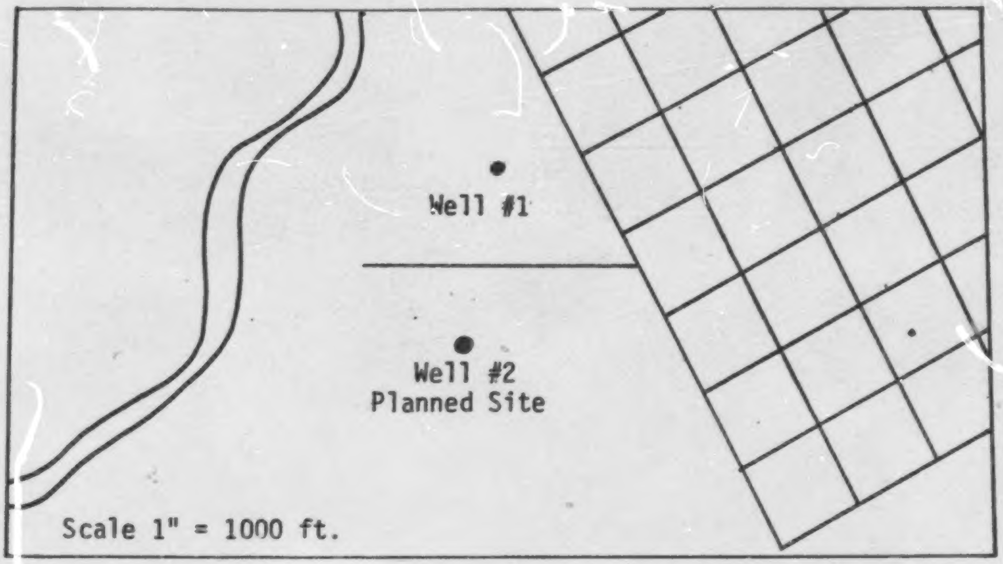
The Record File

The record file for each well drilled whether in use or retired should be maintained and include:

1. Drilling Records
    a. Sieve analysis
    b. Water analysis
    c. Drillers logs
2. Equipment Records
    a. Pump performance curves
    b. Purchase records
    c. Parts literature
    d. Maintenance records
3. Well Records
    a. Specifications of components
    b. Maintenance records
    c. Yield records
    d. Drawdown graphs and related calculations
4. Aquifer Records
    a. Dimensions and related calculations
    b. Static water level
    c. Recharge and recovery records
    d. Water quality records

These record file contents can then be used when planning a new well. For examples given the following selected records, what problems (if any) would the chosen site for Well #2 encounter?

1. Area Map



2. Well #1 Data

Depth: 1400 ft. Diameter 3'

Fractured limestone formation - 160 feet thick

Static water level 1000'

Transmissibility = 66,000

Storage coefficient = .0037

Maximum pumped time 20/24 hrs.

Well efficiency = 89%

Pumping rate = 500 gpm

Initial pumping test = 3 days continuous pumping results showed continuous aquifer

3. Water Quality Records:

   Little change in water quality over past 20 years.

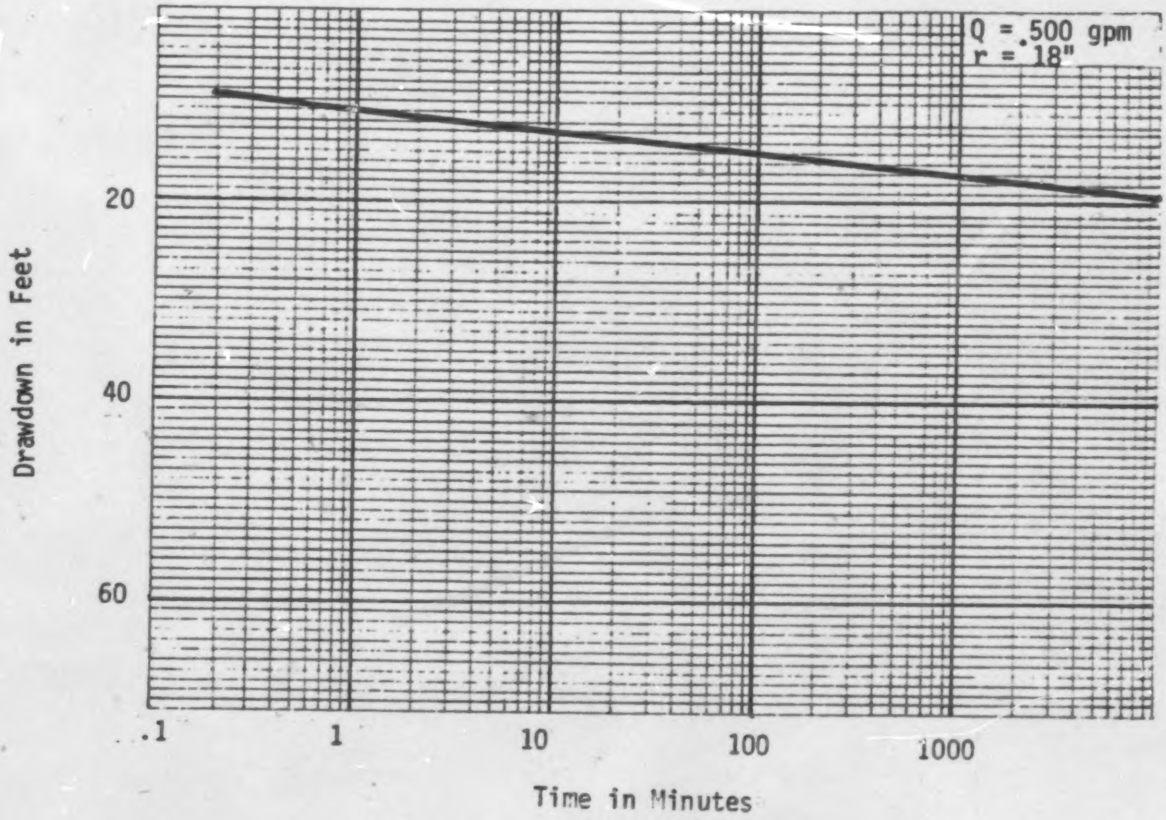
4. Well Maintenance

   No major repairs

5. Time drawdown curves

   a. Only normal variation from year to year

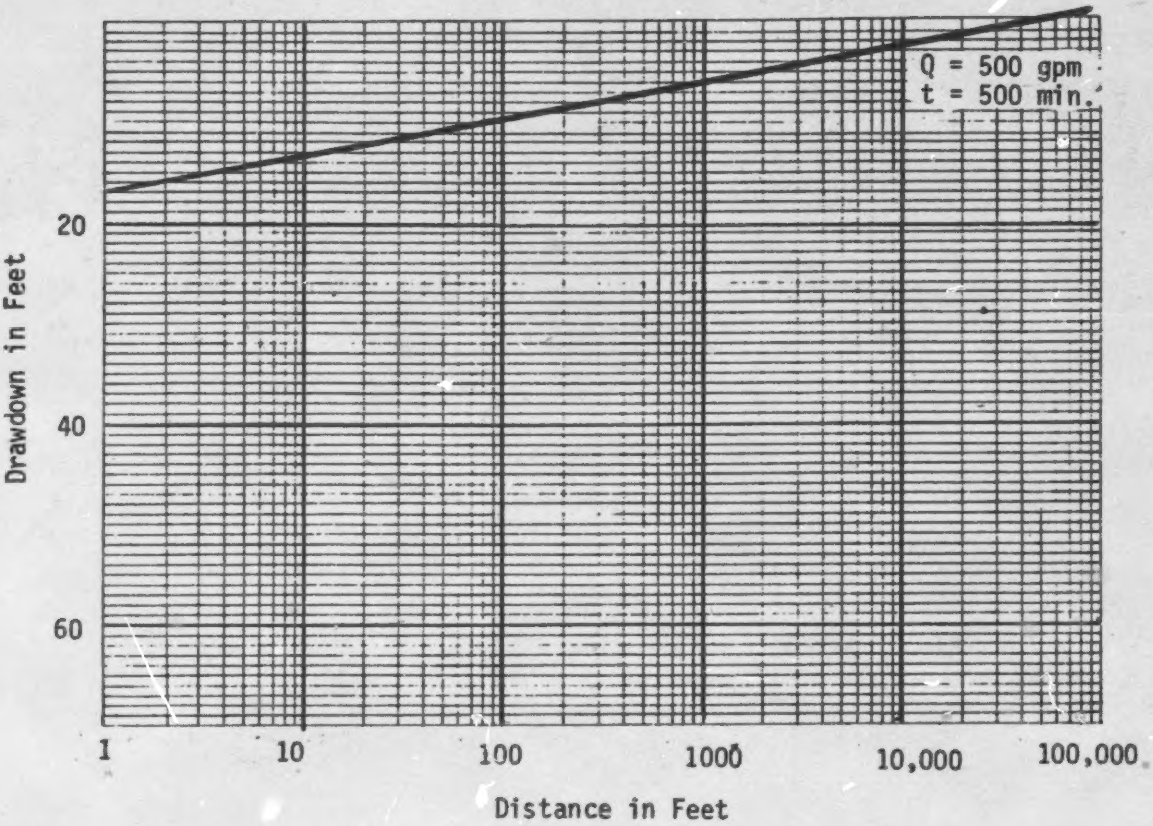
   b. Most recent below



6. Distance Drawdown Curves

   a. Only normal year-to-year variation.

   b. Most recent below.



7. Design Plan for Well #2

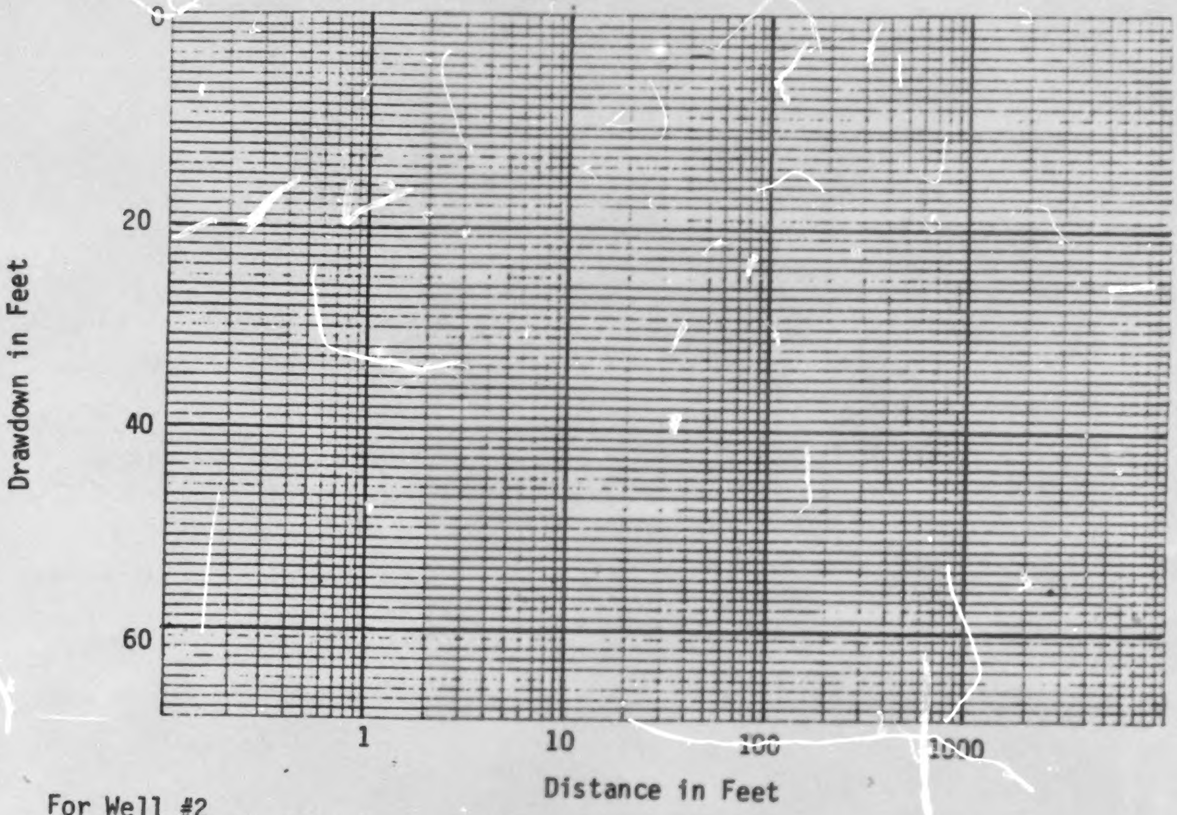
Depth approximately 1400 ft. Well planned to be similar to #1.

Pumping rate = 750 gpm

Planned maximum pumping time of both wells together 8/24 hrs.

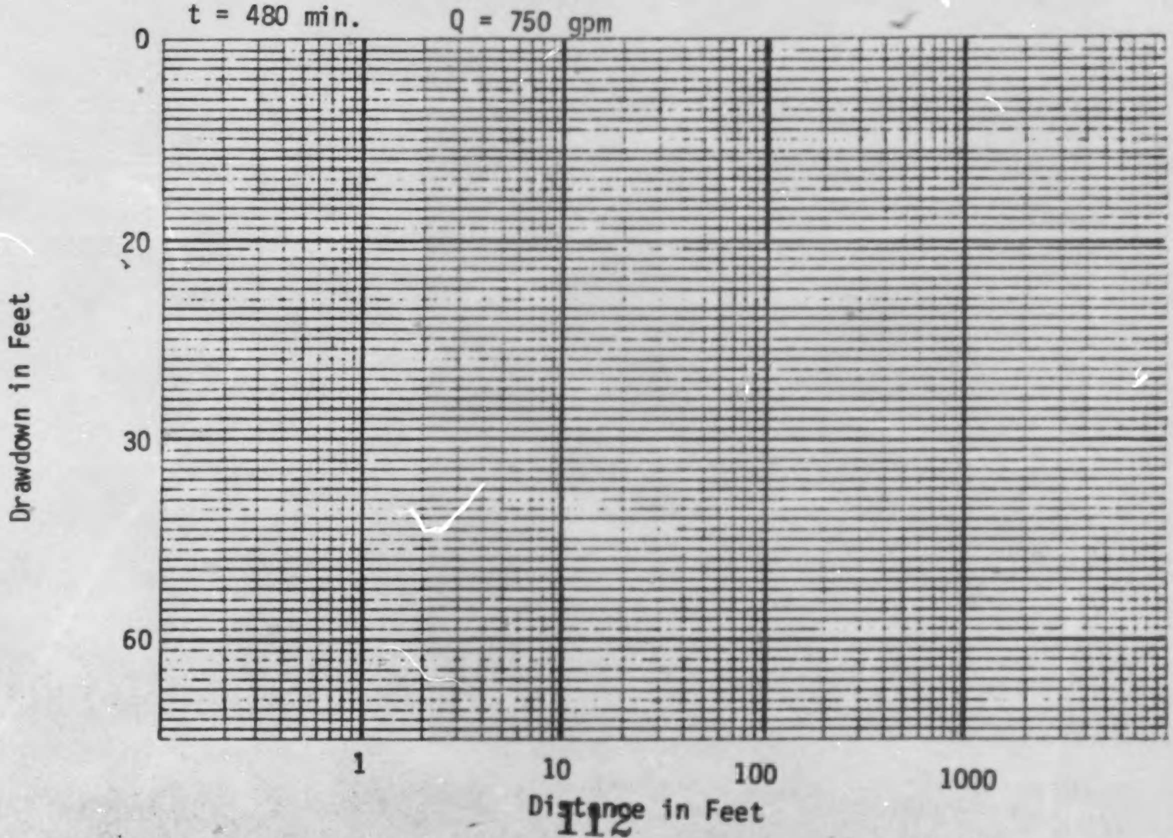
For Well #1

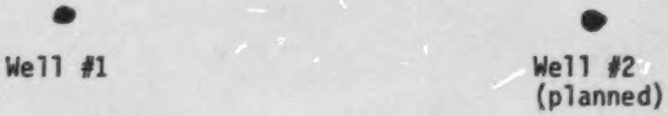
t = 480 min.   Q = 500 gpm

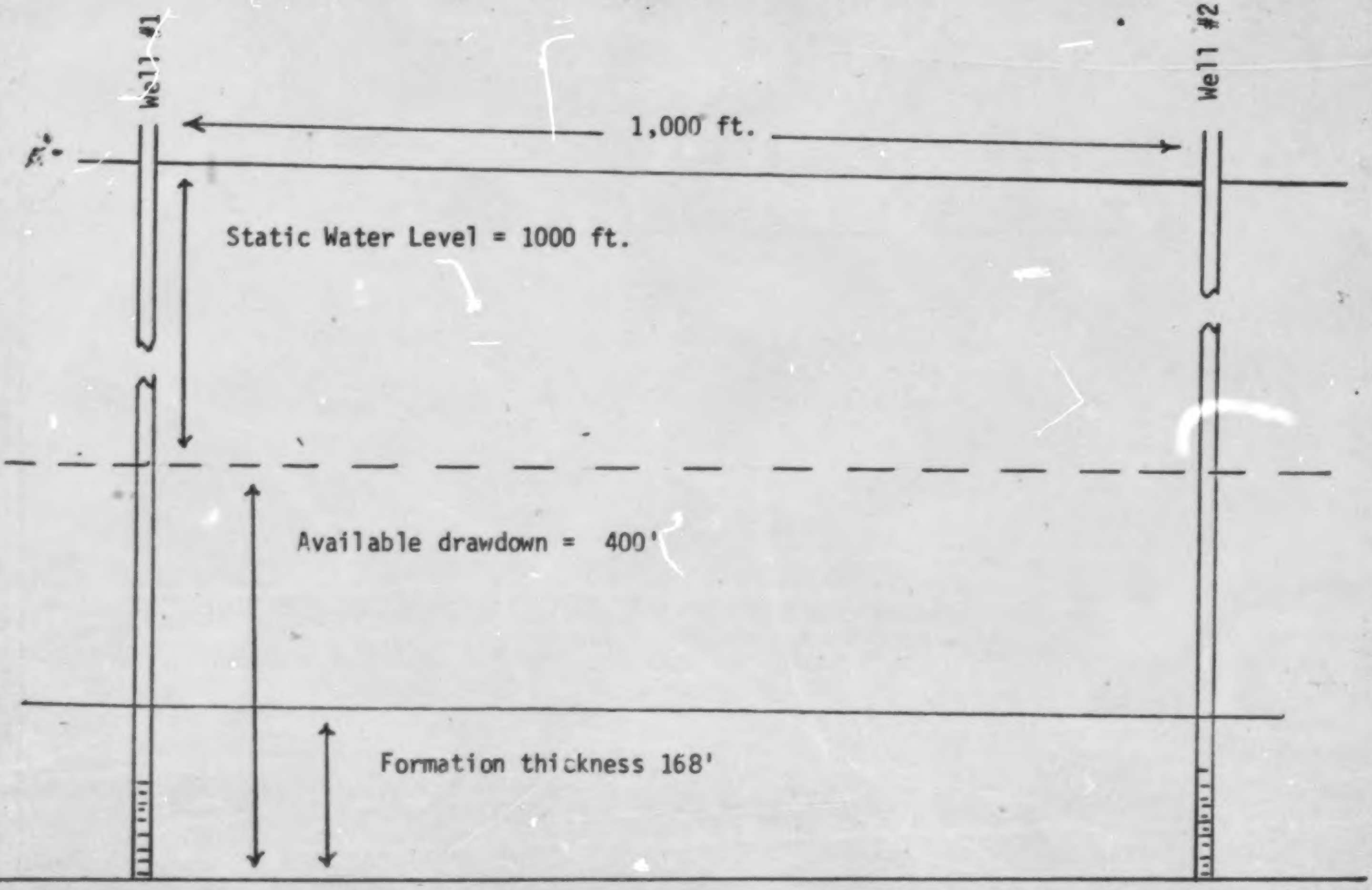


For Well #2

t = 480 min.   Q = 750 gpm




Well #1
Well #2
(planned)


Well #1
Well #2 (planned)
1,000 ft.
Static Water Level = 1000 ft.
Available drawdown = 400'
Formation thickness 168'

Contracts and Specifications

A. General Types of Contracts

Two end points exist in contracting philosophy - the pure performance contract, and the pure comprehensive specifications contract. In reality most contracts are a blend of the two philosophies.

1. Performance Contract
    a. A pure performance contract states only the final result desired and leaves the design and construction details up to the contractor.
    b. Advantages
        1. Full responsibility on contractor - no opportunity extra costs because of poor design.
        2. Opportunity for contractors to use innovative design and construction methods that may result in lower overall costs.
    c. Disadvantages
        1. If sufficient background information is not made available, costs may be higher due to risk factor.
        2. Possibility exists for sub-standard design/construction for long-life, maintenance-free operation. This can be minimized by requiring an operation/maintenance contract for several years after construction.
2. Comprehensive-specifications contract
    a. A purecomprehensive-specifications contract prescribes in detail what to do and how to do it. All details of design and construction methods are specified by the owner.
    b. Advantages
        1. The contractor has less responsibility relative to the responsibility inherent in a performance contract. This can result in a lower price providing the cost of materials and construction methods specified provide the best values.

2. High-quality work and materials probably will result, depending on the competency of the designer.

c. Disadvantages

1. More work must be done by the designer/owner than under a performance contract.

2. The owner/designer takes full risks for performance of facilities as specified.

3. Combination contract

a. Most contracts contain aspects of both end-point types as described above. A well may be designed in detail, but the construction methods may be left to the contractor.

b. A variation of the two end-point approaches is lump sum versus unit prices for work to be done. All degrees of combinations are available. For instance:

1. Construct one well field to deliver xx gpm. Lump sum __________

2. Construct sufficient wells to deliver xx gpm. Price per well ______

3. Construct sufficient wells to deliver xx gpm. Unit prices:

Drilling ______/ft.

Casing_________/ft.

Screen ________/ft.

Etc.

4. Perform drilling as directed:

Cost per hour _____

Cost of materials_____

c. The choice of contract approach is dependent on many factors including:

1. Completeness of background data available. If test holes, detailed logs, etc. are available at each well location to permit final design at each well site, then the lump sum versus the unit price approach is generally preferred. However if final designs cannot be made, then the unit price approach is much better.
2. Competency of contractor. A "performance" approach should be considered only if the prospective contractors are known to be competent and reliable and will deliver a satisfactory end result
3. Competency of owner or owner's representative. It is possible and sometimes desirable to place design responsibility with the contractor when the contractor has more expertise than the owner.

B. How Design Effects Bid Prices

The examples below illustrate how design can effect bid prices either by requiring unnecessary work or by placing undue risk with the contractor.

1. Well Diameter

Drilling speed, power requirements, torque requirements, and rig size are all dependent on hole diameter. Increasing the diameter from 10 inches to 12 inches results in removal of 44% more material from the hole. Specifying a 20-inch hole instead of an 18-inch hole results in the removal of 23% more material. Recommendation: Use the smallest hole diameter practical commensurate with other good design practices.

2. Unnecessary Materials Requirements

Specifying stainless steel, everdure or other expensive metals when not absolutely required results in unnecessary costs.

3. Unusual Construction Requirements

   Construction techniques such as underreaming, drastic changes in hole diameter, hung liners, difficult grouting, or other construction requirements that are difficult and require highly specialized equipment result in high costs.

4. Misapplication of Equipment

   If the construction technique specified does not match the field conditions high costs result.

5. Over sophistication of design: Examples

   a. Real short screens, say 2' spaced out every 2' where cost of assembly is more than 3' of screen.

   b. Elaborate wellhouse

C. How Specifications Effect Bid Prices

1. Warranties

   a. Sand content

      1. Measure using a centrifugal sand separator.

      2. Do not impose unnecessary constraints. A line-shaft turbine, open impeller has more tolerance to sand than a submersible or closed impeller turbine. Water use is also a contraint (see table next page).

      3. If the well screen opening and gravel pack size is specified in the specifications by the owner, then it is not reasonable to place responsibility for sand content on the contractor.

      4. Recommended sand maximums:

Conditions	Content
a. Flood irrigation, no danger of caving well or damaging pump	2 ppm

Conditions	Content
b. Sprinkler irrigation, cooling systems	2 ppm
c. Homes, municipal, industrial	1 ppm
d. Direct food or beverage processing	1 ppm

5. Some wells produce a small amount of sand when the pump is first turned on. Solutions: (1) increase cycling interval, (2) install sand separator.

b. Alignment and plumbness

1. Plumbness is very rarely a critical factor. Even line-shaft turbines operate satisfactorily when inclined from the vertical. On the other hand, poor alignment can effect the operation of line-shaft turbines because of excessive shaft wear.

2. Alignment test

   40-feet long dummy with a diameter 1/2 inch less than the ID of the casing should pass freely to the lowest pump setting. Or the casing shall not deviate more than 2/3 its diameter in any 100-foot segment.

c. Well yields

It is generally not feasible to require the contractor to guarantee well yield, especially if the well design is specified by the owner. Yield guarantees usually result in a large increase in cost.

d. Performance warranties

It is feasible to require the contractor to guarantee the pumps and controls against defects in materials and factory workmanship for some reasonable time period such as one year. It is not justified in my opinion to require the contractor to guarantee well performance. Evaluation of future well performance should be made before acceptance of the well. Excessive sand pumping can sometimes be solved by additional or different development methods. Nearly all other factors effecting long-term well performance such as aquifer constants and water quality are beyond the contractor's control.

2. Unit Prices

The breakdown and selection of unit prices can effect final costs as shown by the following examples:

a. In a test drilling program unit prices should include (1) drilling and (2) furnishing and setting casing separately. Some test holes may not be cased.

b. For test pumping, have one unit price for installing pump, conducting the minimum hours of pumping, and removing pump. Have another unit price for continuing the pump test longer than the minimum time.

c. In general, where conditions are well known and objectives clearly defined use fewer unit prices and approach a lump sum contract. Where conditions are relatively unknown and many field decisions must be made, use many unit prices to provide flexibility.

Water Supply - Wells
Handout C-2

WELL-TO-SYSTEM CONNECTION AND EVALUATION

Well Efficiency and Cost

Two types of cost are involved in obtaining a supply of water from a well: (1) the direct pumping cost for power (operating cost), (2) indirect cost arising from the investment and maintenance costs of the well system. Both of those types of costs are influenced by design of well and pump.

The direct cost for power can be calculated by means of an applicable formula. When the source of power is electricity, the following formula is used to determine the cost of pumping per hour:

$$(1)\ \text{Cost per hour (cents)} = \frac{\text{gpm} \times \text{tdh} \times 0.746 \times \text{kwh cost}}{3960 \times \text{efficiency}}$$

In which

gpm - Rate of pumping in U. S. gallons per minute

tdh - Total dynamic head, in feet, which includes the distance from the pump discharge down to the water level in the well when pumping, plus the elevation or pressure in feet against which the water is pumped beyond the pump discharge, plus the head due to friction and turbulence of flow.

0.746 = A constant to convert brake horsepower to kilowatt-hours.

kwh cost - Cost per kilowatt-hour for electricity, in cents.

3960 = A constant for conversion of units

Efficiency = Wire-to-water efficiency which is the overall pump efficiency multiplied by the efficiency of the motor.

When a pump is powered by a motor using diesel, gasoline or LP gas for fuel, the same formula is used in the following modified form:

$$(2)\ \text{Cost per hour (cents)} = \frac{\text{gpm} \times \text{tdh} \times K \times \text{fuel cost per U. S. gallon (cents)}}{3960 \times \text{overall pump efficiency}}$$

In which

K = The fuel requirement in U. S. gallons per horsepower-hour. This is commonly assumed to be 0.065 for diesel, 0.088 for gasoline and 0.110 for LP gas with motors of average efficiency.

In the above formulas the result can be changed to "Cost per 1,000 gallons" by replacing gpm with the constant 16.67.

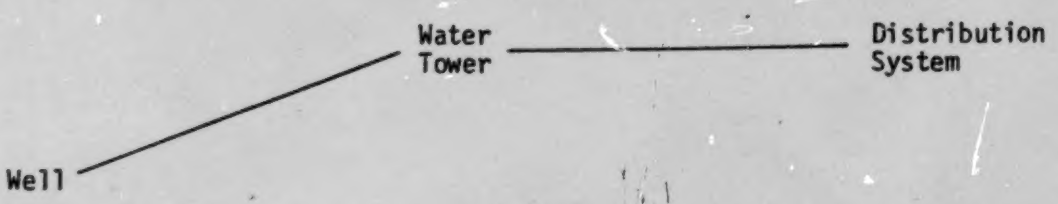
On the following page there is a nomogram which can be used to determine quickly, without calculation, the pumping cost per 1,000 gallons when using electric, diesel or gasoline power.

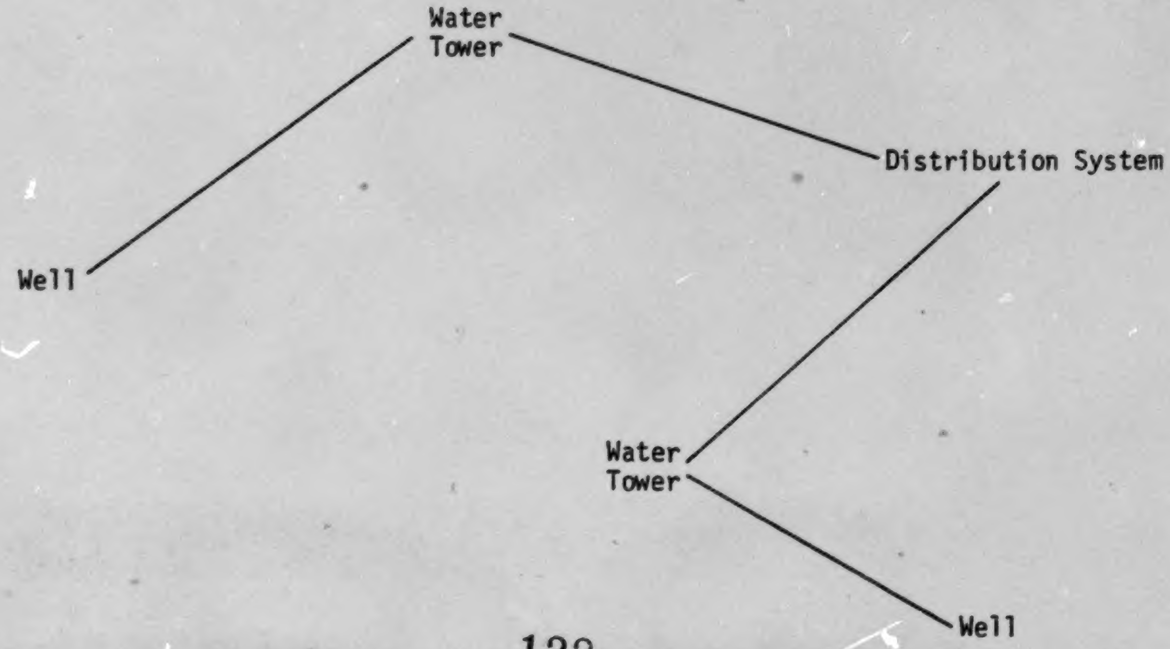
Effect of Efficiency on Cost

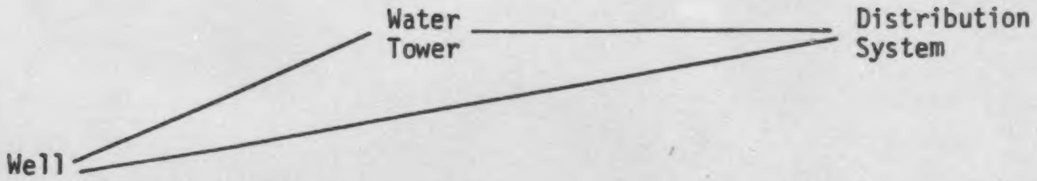
From these formulas it can be seen that the cost of pumping is directly affected by the drawdown (lowering of the water level) in the well when pumping because this is a part of the total dynamic head.

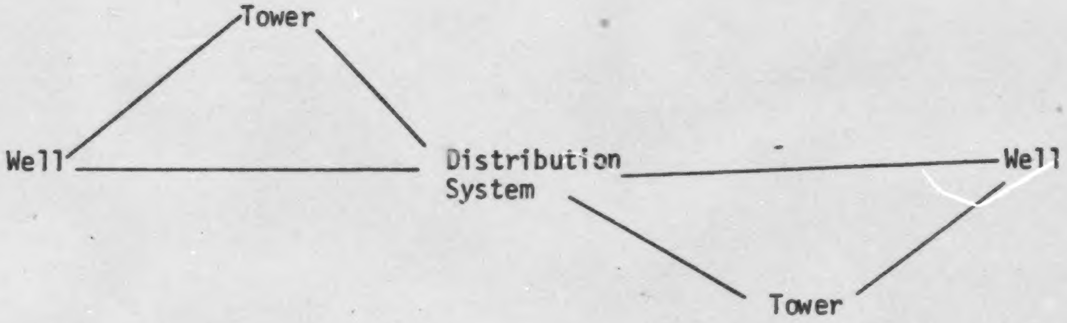
Well to System Connection

The two basic well-system connections are shown in the following diagrams.


Water Tower
Distribution System
Well


Water Tower
Distribution System
Well
Water Tower
Well


Water
Tower
Distribution
System
Well


Tower
Well
Distribution
System
Well
Tower

Use of Towers

Towers are used to maintain a constant pressure and a reserve water supply in case of fire.

Supply Evaluation

In evaluating the water supply system the fire protection demands are the first consideration.

WATER SUPPLY - WELLS: TRANSPARANCY LIST

Well Technology and Basic Maintenance (#1 - 20)

#1: Hydrologic Cycle

#2: Movement of water to aquifer

#3: Confined vs. water table aquifer

#4: Aquifer pollution

#5: Exploration methods

#6: Classification of rock

#7: Porosity, permeability, transmissibility and specific yield

#8: Well design - diameter and depth

#9: Well design - sanitary seal

#10: Well design - screens

#11: Well design - screens

#12: Well design - pumps

#13: Well construction - dug and auger

#14: Well construction - Cabel tool and rotary drilled

#15: Well development

#16: Well development

#17: Incrustation

#18: Corrosion

#19: Measuring drawdown - measurements

#20: Measuring drawdown - Records and problem solving

Evaluation of Well Performance (#21 - 27)

#21: Porosity, permeability, transmissibility and storage coefficient

#22: Drawdown and cone of depression with respect to time and distance

#23: Distance drawdown plot

#24: Time drawdown plot

#25: Well interference vs. drawdown

#26: Pumping rate vs. drawdown

#27: Problem prevention

Basic Well Management (#28 - 30)

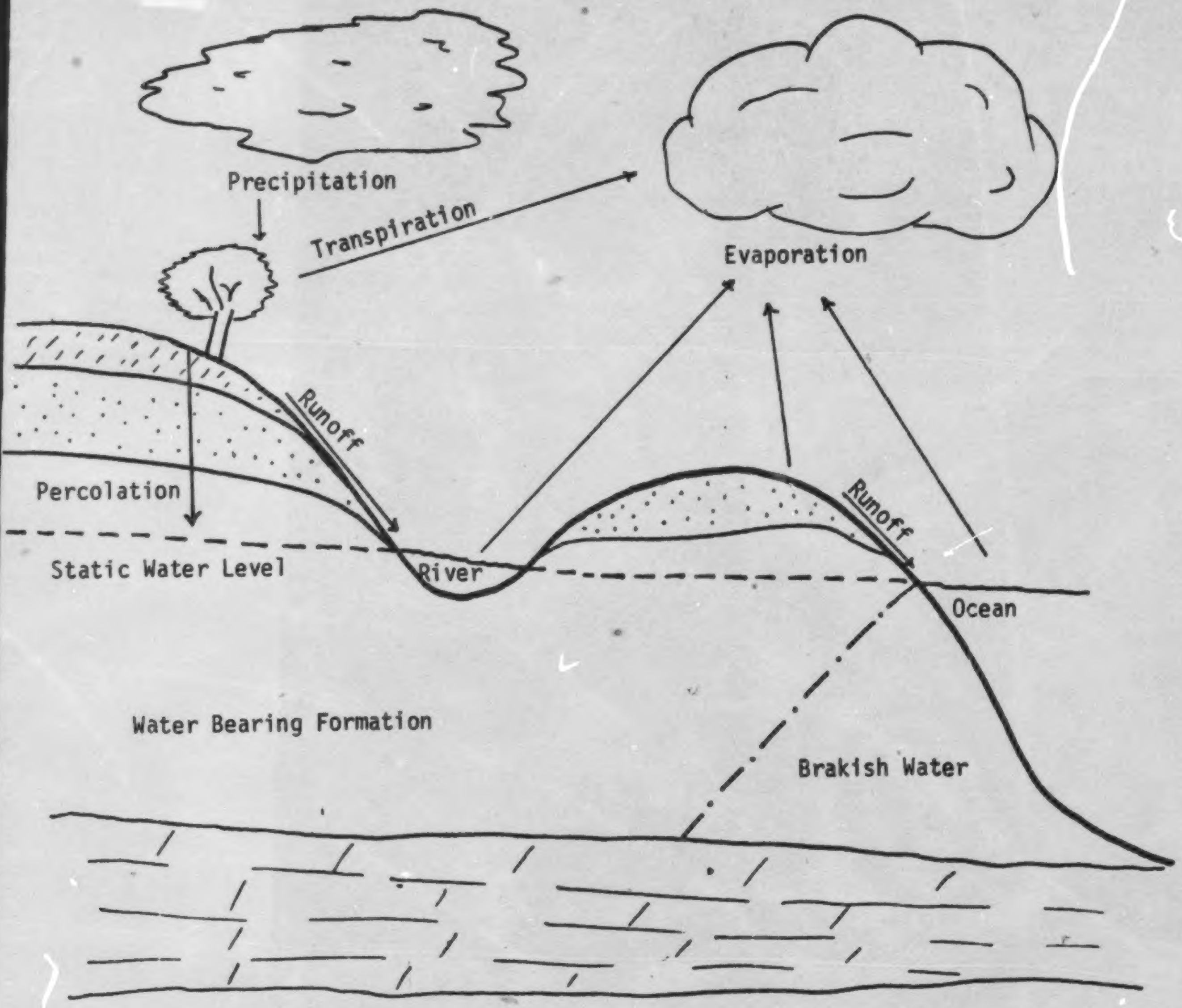
#28: Record file

#29: Well placement

#30: System capacity

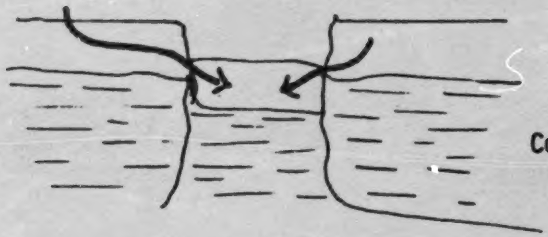
THE HYDROLOGIC CYCLE

#1.

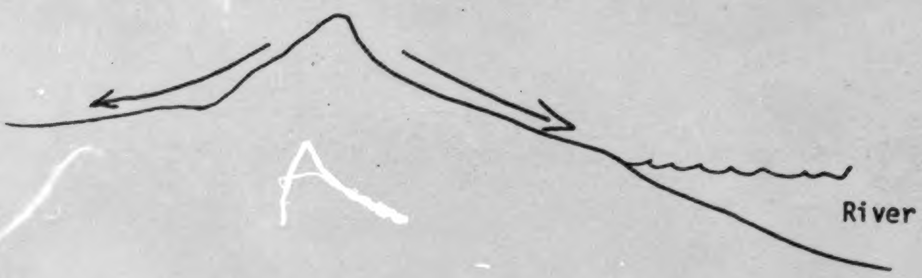

Precipitation
Transpiration
Evaporation
Runoff
Percolation
Static Water Level
River
Runoff
Ocean
Water Bearing Formation
Brakish Water

MOVEMENT OF WATER
TO AQUIFER AFFECTED BY:

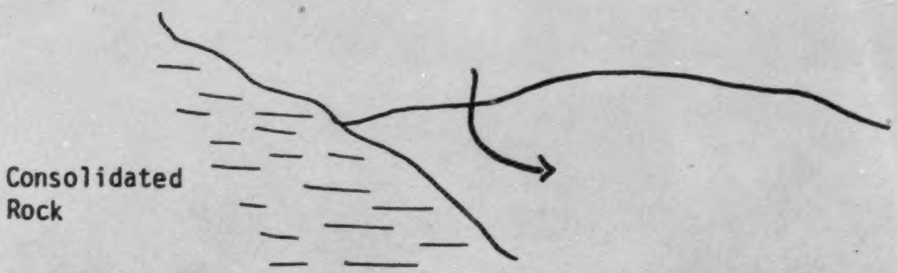
FAULTS


Consolidated Rock

SLOPE OF THE GROUND SURFACE



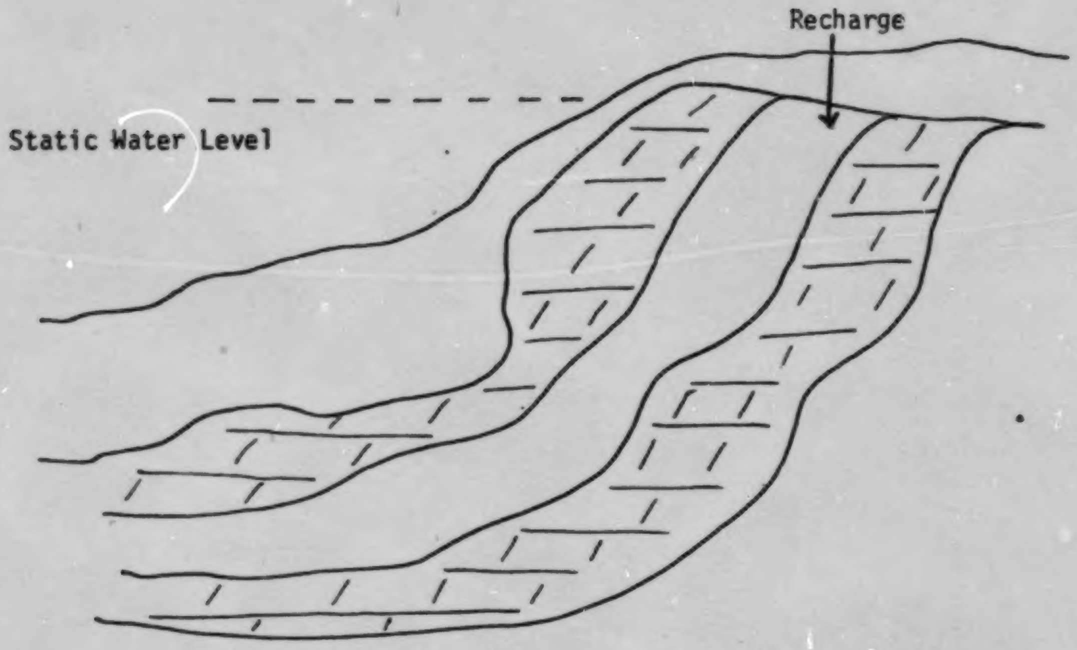
IMPERVIOUS GEOLOGIC FORMATIONS


Consolidated
Rock

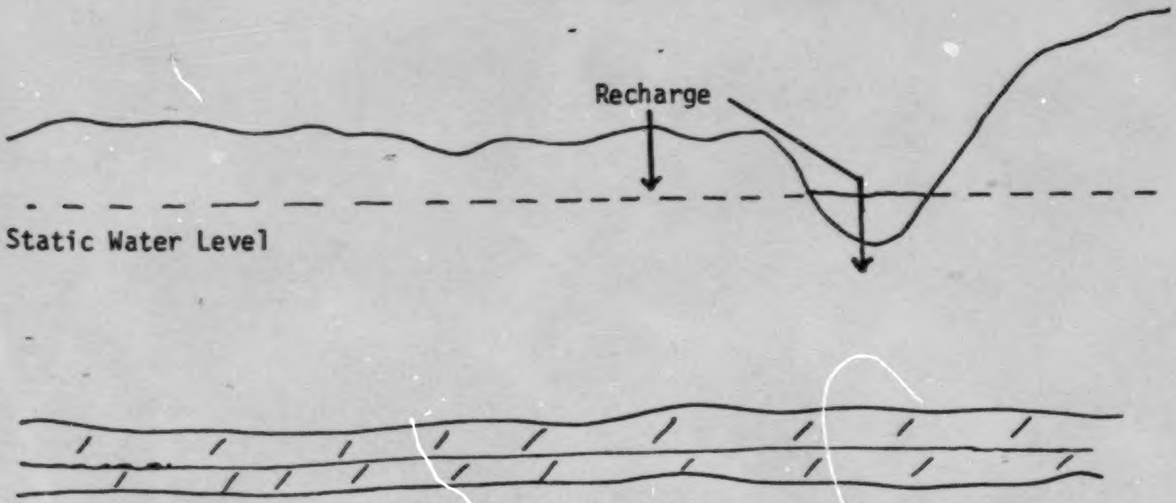
#3.

AQUIFER TYPES

ARTESIAN AQUIFER


Recharge
Static Water Level

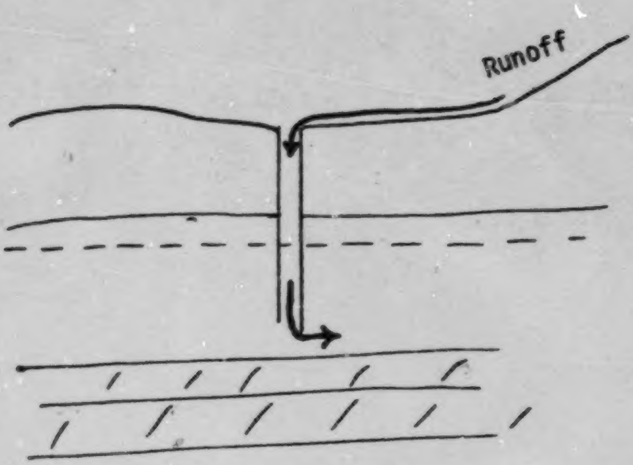
WATER TABLE AQUIFER


Recharge
Static Water Level

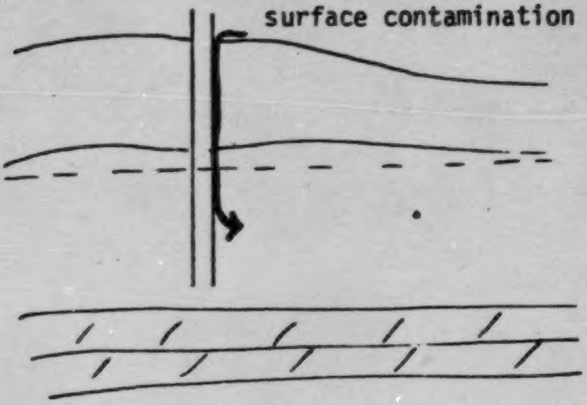
#4.

AQUIFER POLLUTION

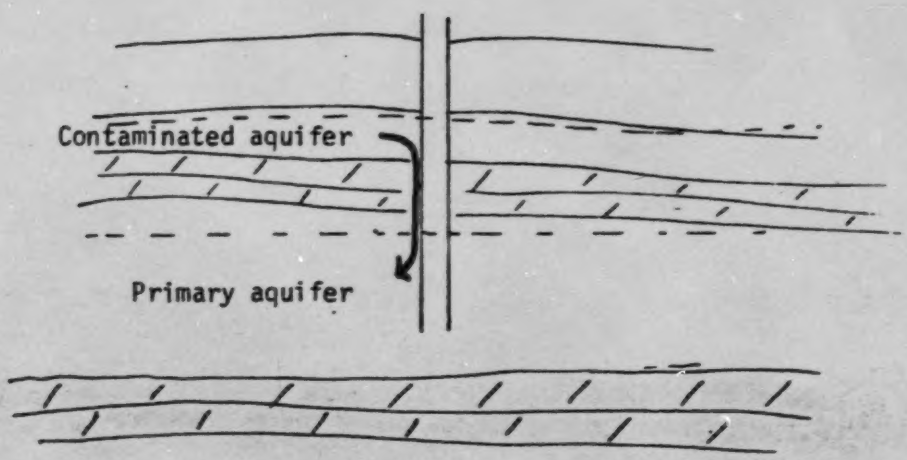
Old Well



Unsealed Well


surface contamination

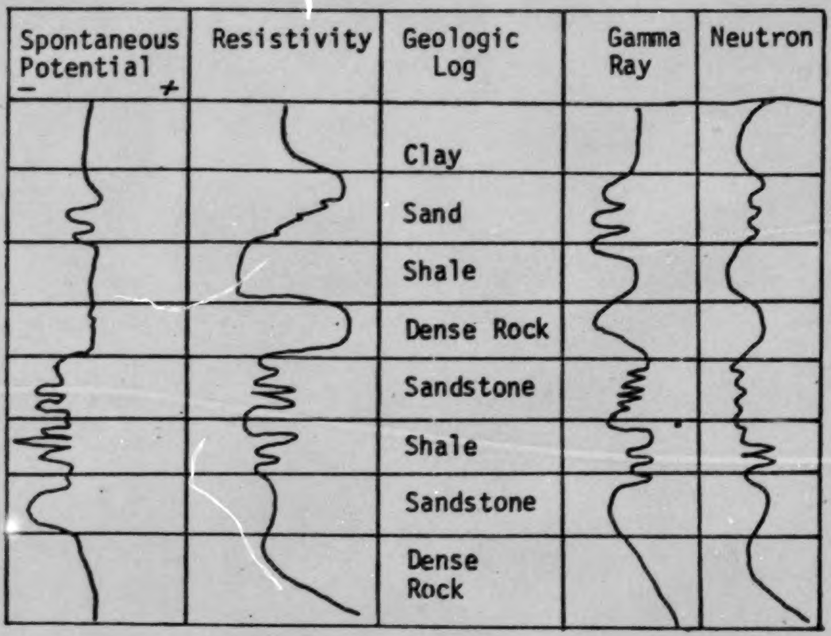
Aquifer Mixing


Contaminated aquifer
Primary aquifer

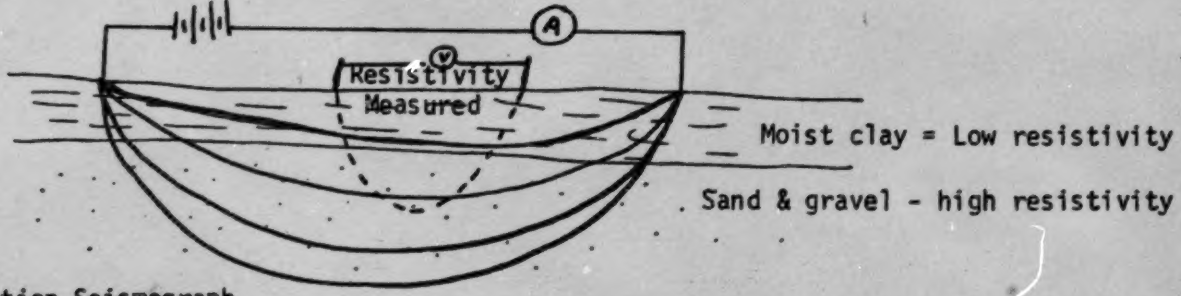
#5.

EXPLORATION METHODS

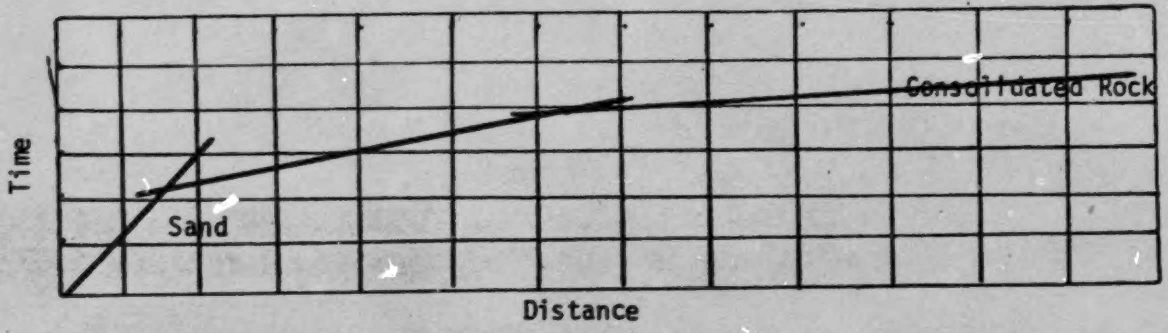
Geophysical Logging


Spontaneous Potential
−
+
Resistivity
Geologic Log
Gamma Ray
Neutron
Clay
Sand
Shale
Dense Rock
Sandstone
Shale
Sandstone
Dense Rock

Surface Resistivity


A
V
Resistivity Measured
Moist clay = Low resistivity
Sand & gravel - high resistivity

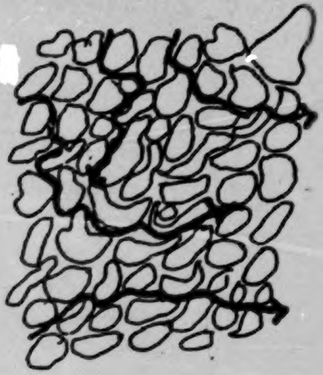
Refraction Seismograph



CLASSIFICATION OF ROCKS

SEDIMENTARY

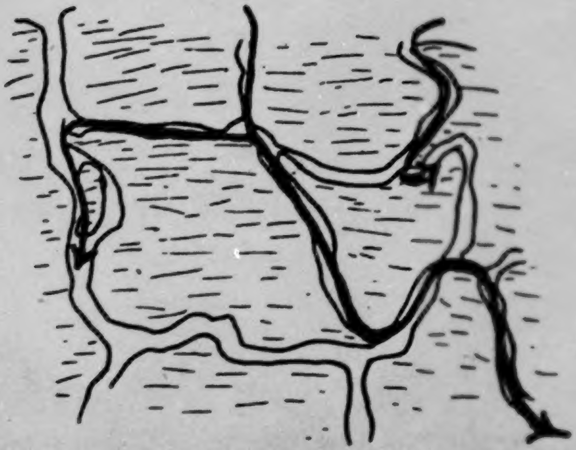
(SAND & GRAVEL)



(CLAY)

Slow movement due to natural properties of clay.

(LIME STONE)



Water wears away stone making water ways

IGNEOUS ROCK

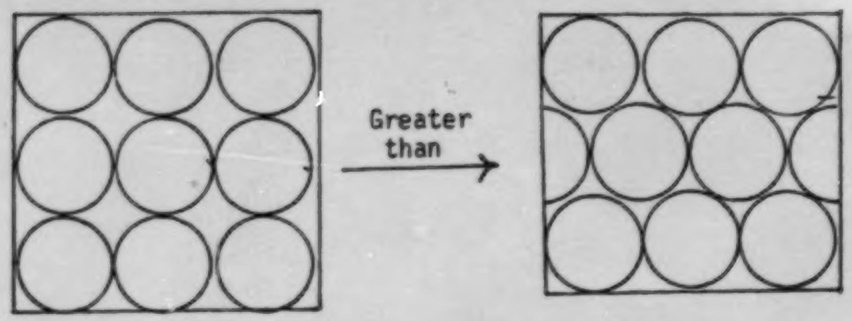
AND

METAMORPHIC ROCK

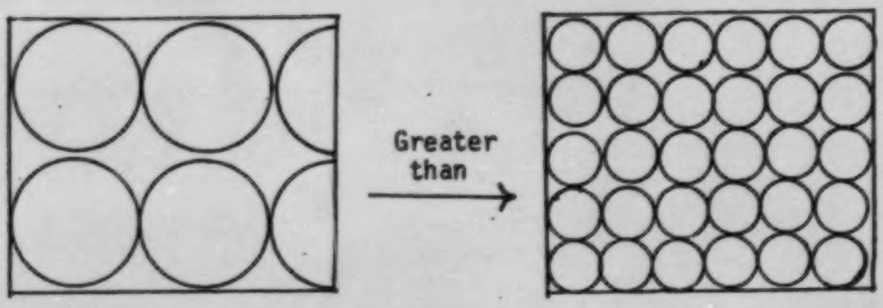
No movement except in cracks

#7.

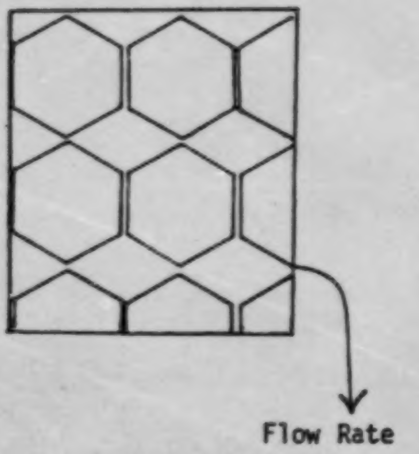
TERMINOLOGY


Greater than

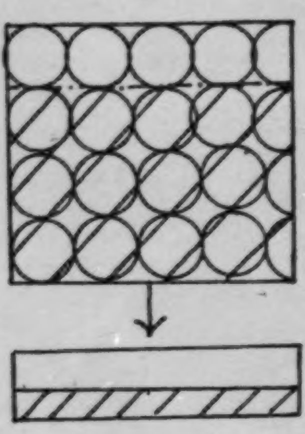
POROSITY


Greater than

PERMEABILITY



TRANSMISSIBILITY



SPECIFIC YIELD

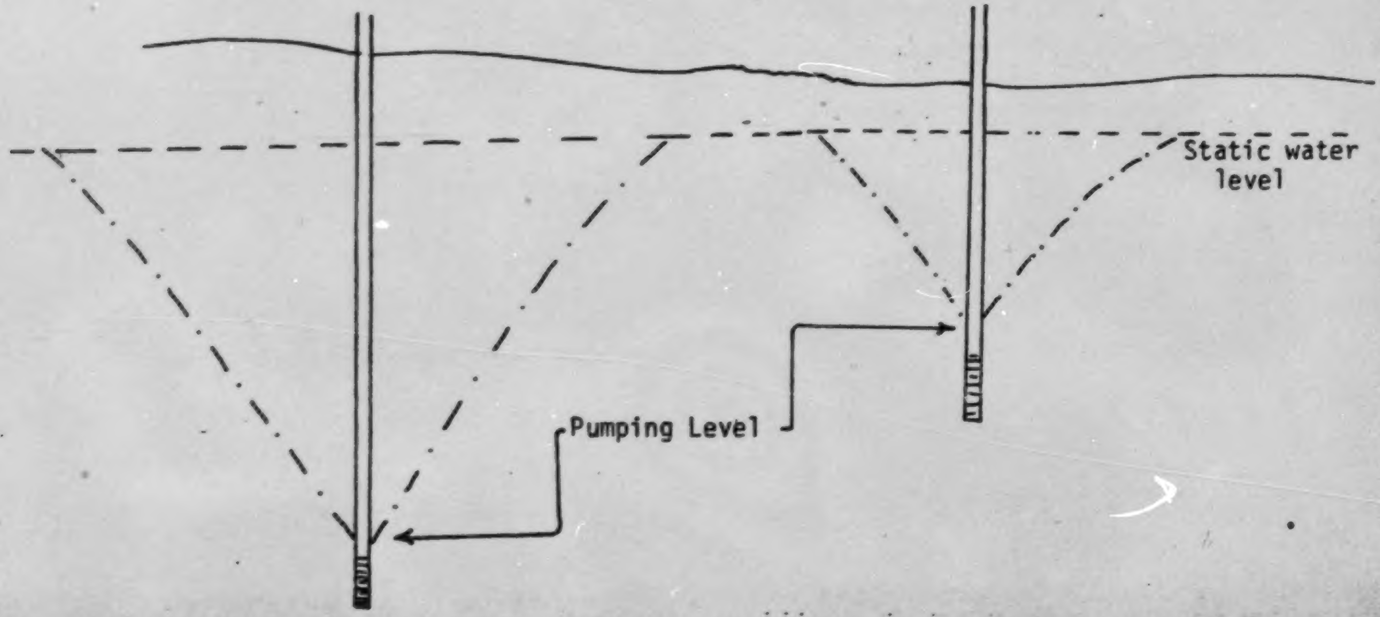
WELL DESIGN

Well Diameter

WELL DIAMETERS						
6"	12"	18"	24"	30"	36"	48"
100	110	117	122	127	131	137
--	100	106	111	116	119	125
--	--	100	104	108	112	117
--	--	--	100	104	107	112
--	--	--	--	100	103	108
--	--	--	--	--	100	105

Well Diameter vs. Yield Ratio in %

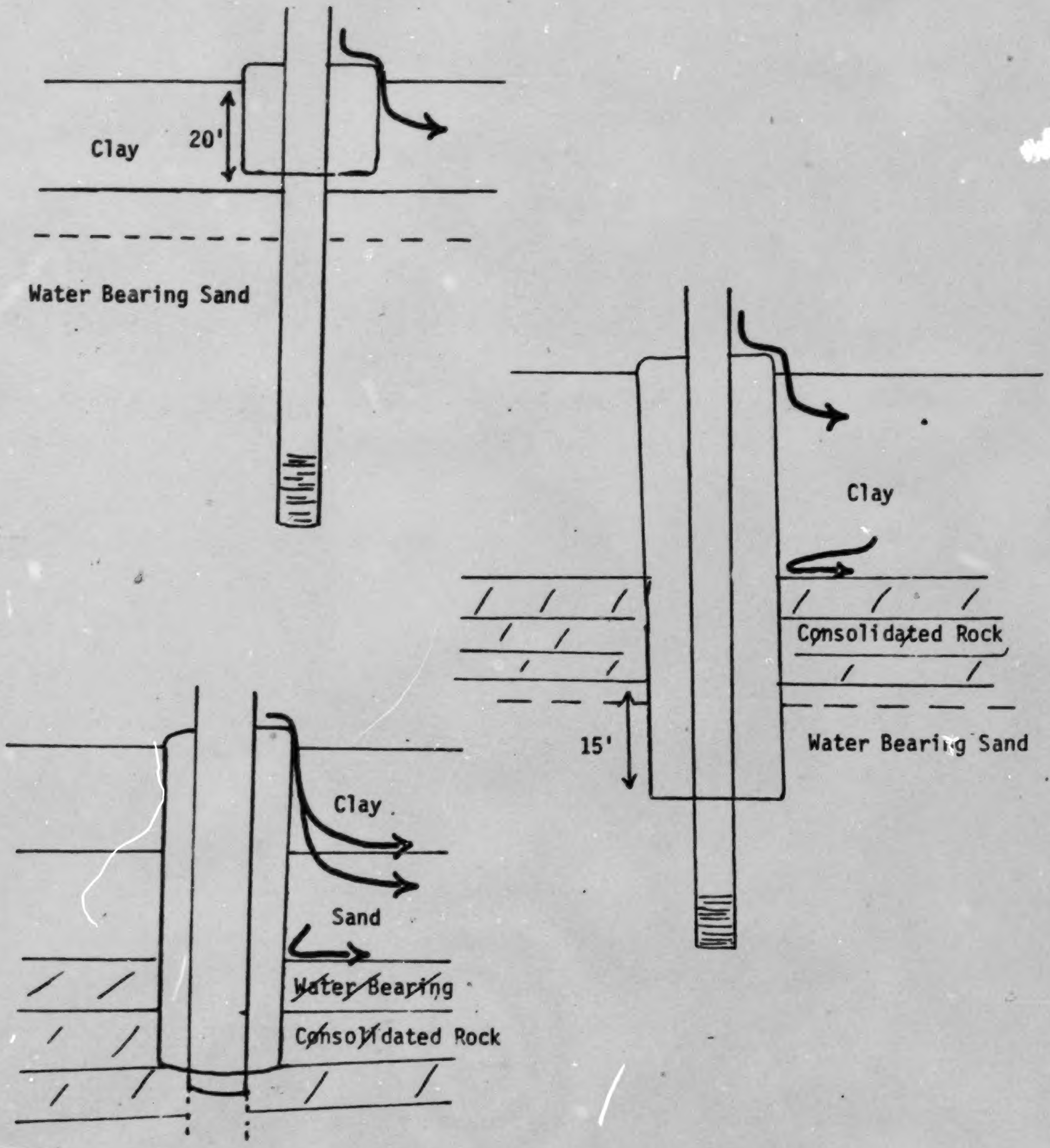
Well Depth


Static water level
Pumping Level

#9.

WELL DESIGN

- Sanitary Seals -

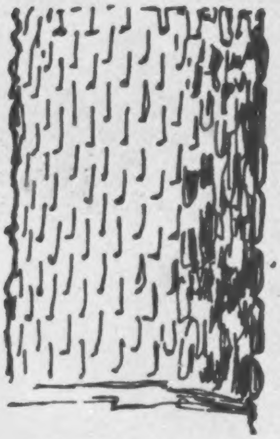

Clay
20'
Water Bearing Sand
Clay
Consolidated Rock
15'
Water Bearing Sand
Clay
Sand
Water Bearing
Consolidated Rock

#10.

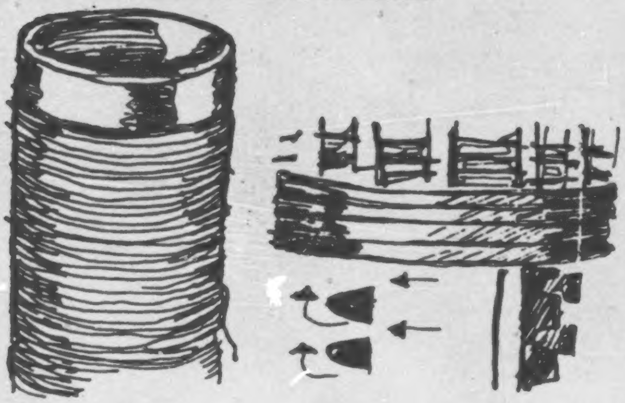
WELL DESIGN

- Screen Types -

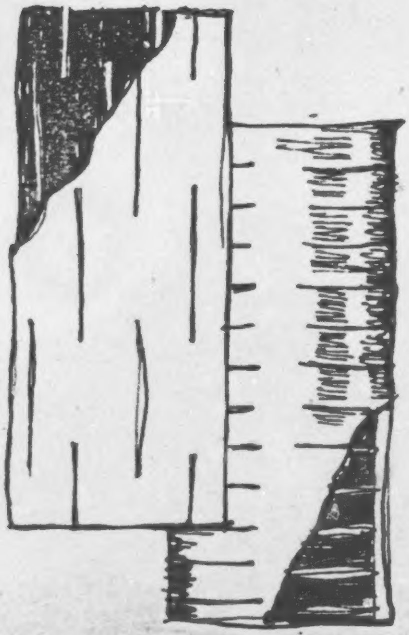
Shutter Screen



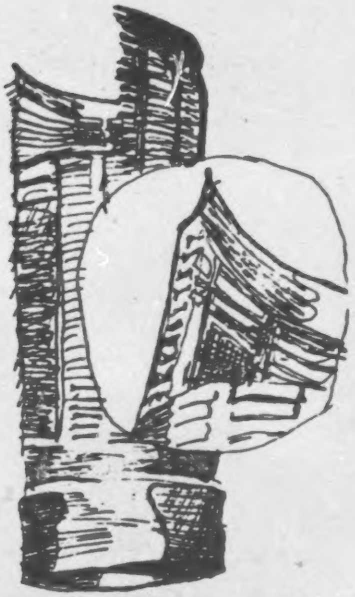
Continuous Wire Wrap



Slotted Casing



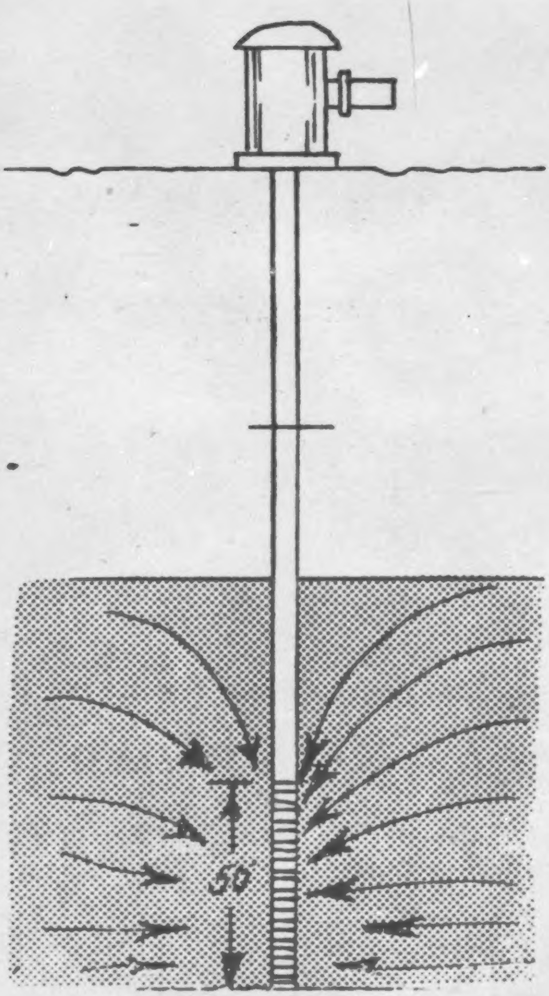
Double Louvered

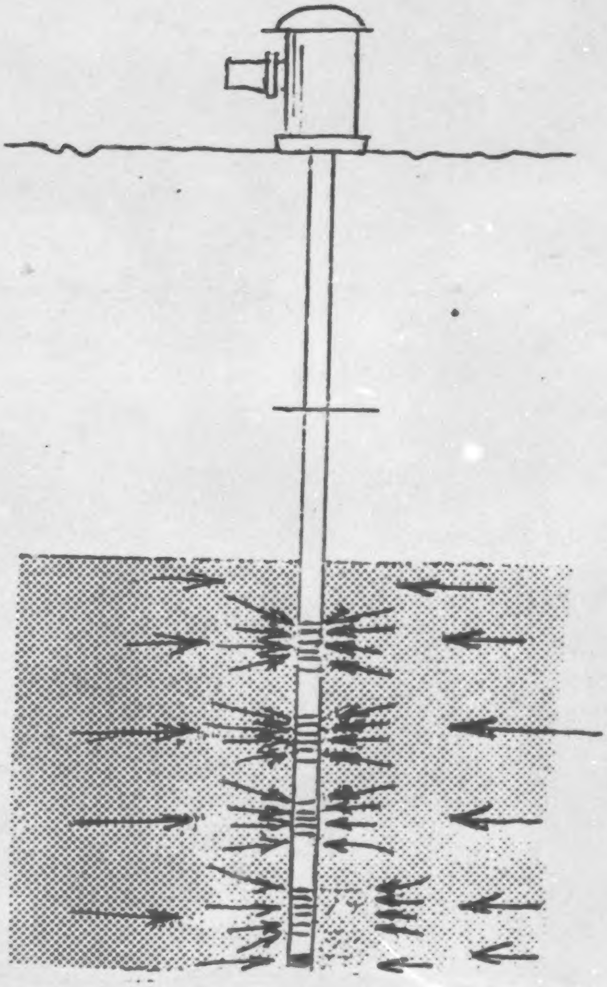


#11.

WELL DESIGN

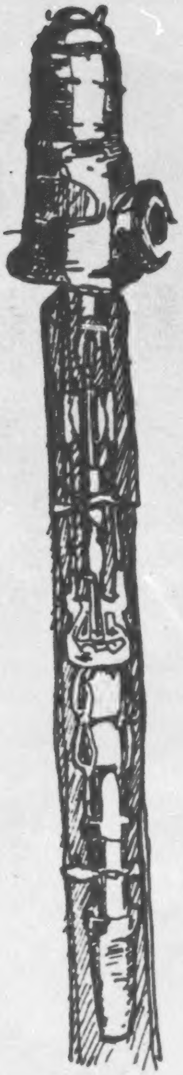
- Screen Placement -



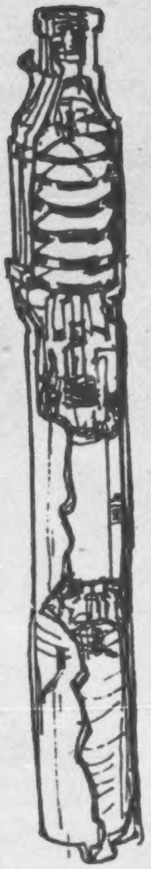


WELL DESIGN

- Pumps -



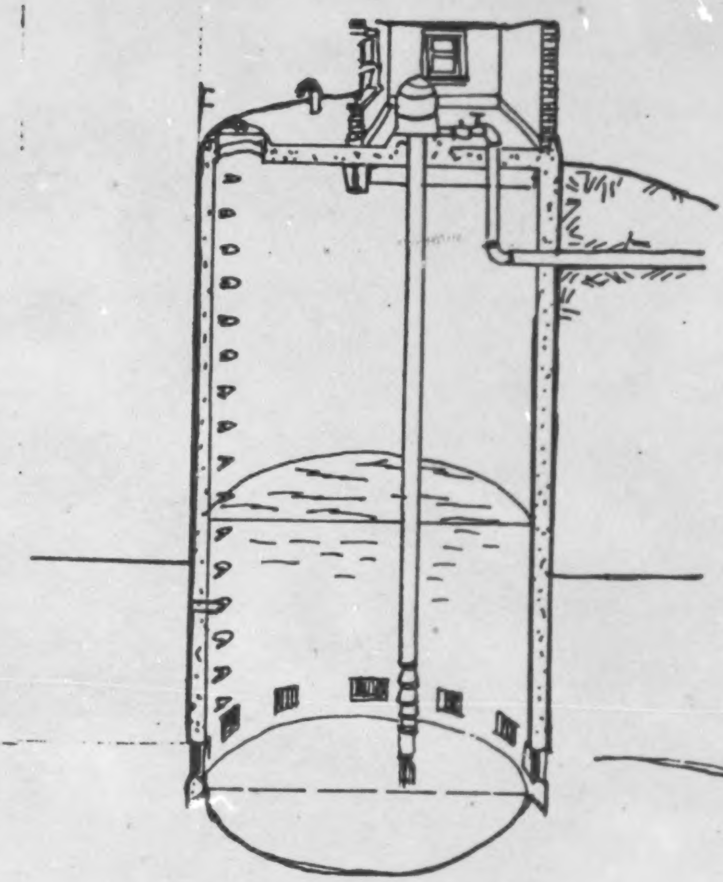
Vertical
Turbine
Pump



Submersible
Pump

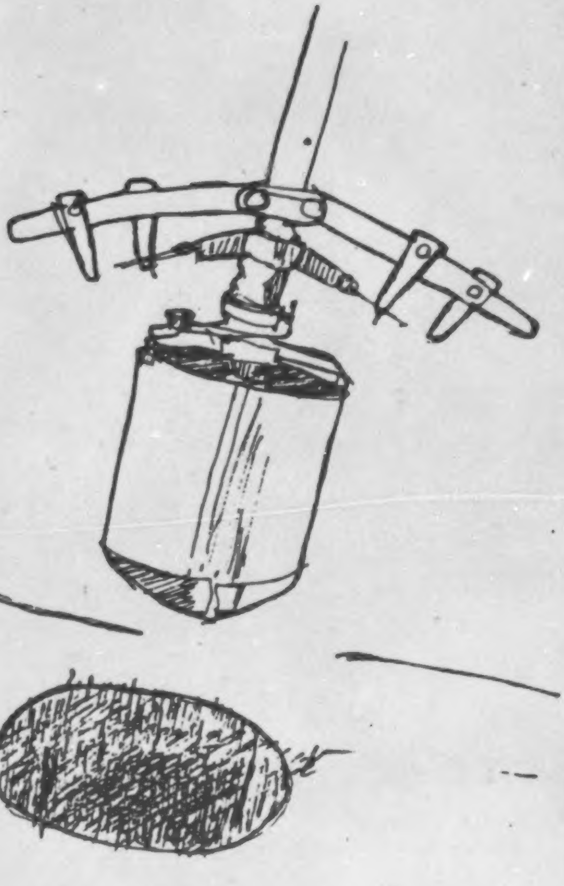
#13.

WELL CONSTRUCTION



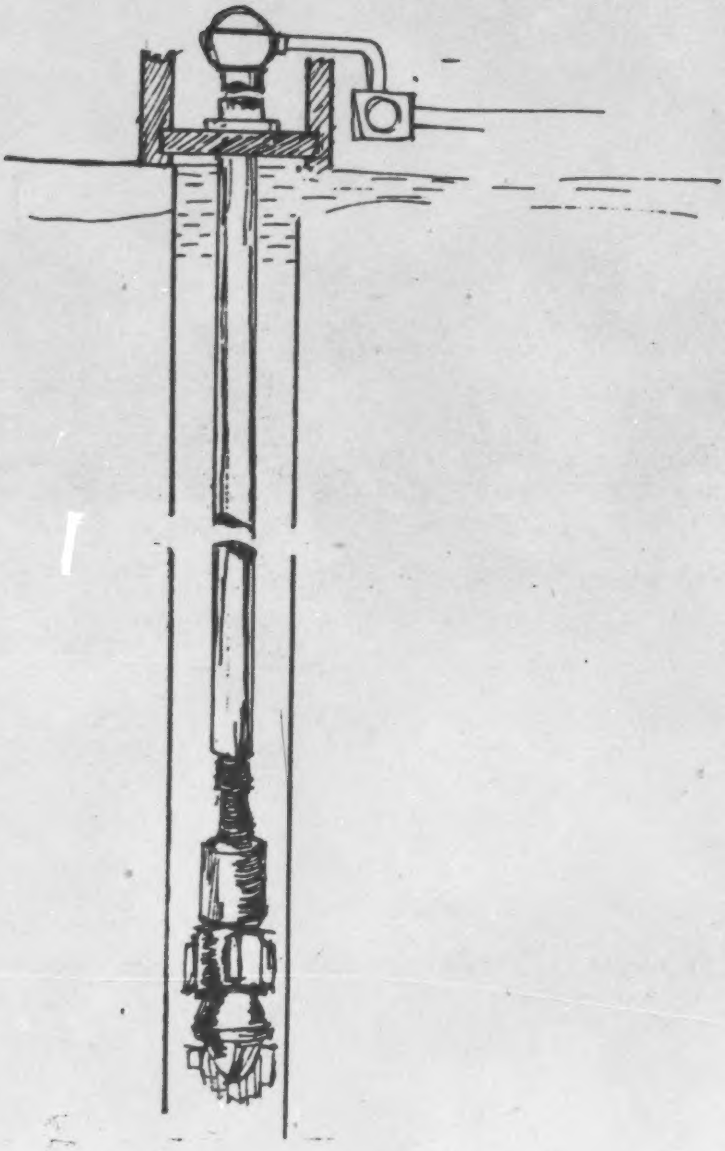
COMPLETED AUGERED OR DUG WELL

WELL AUGER



#14.

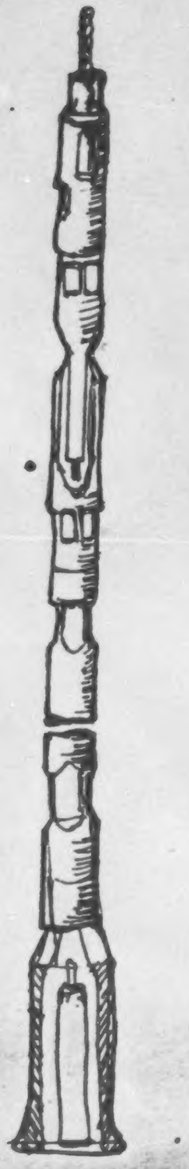
WELL CONSTRUCTION



ROTARY DRILLING

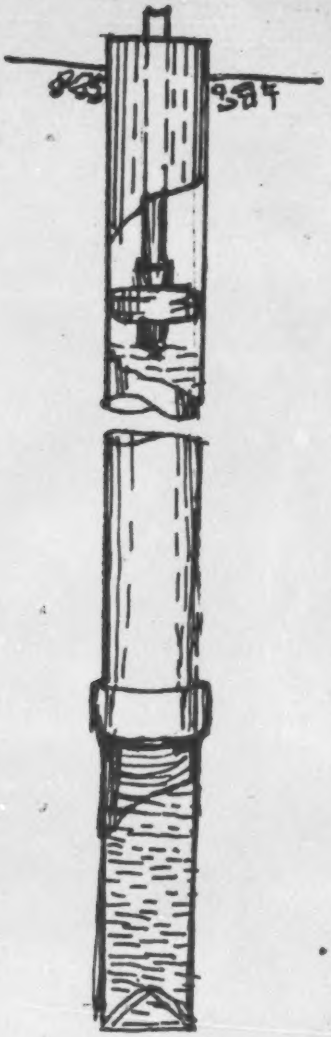
1. MUD
2. WATER
3. AIR
4. REVERSE

CABEL TOOL
PERCUSSION DRILLING



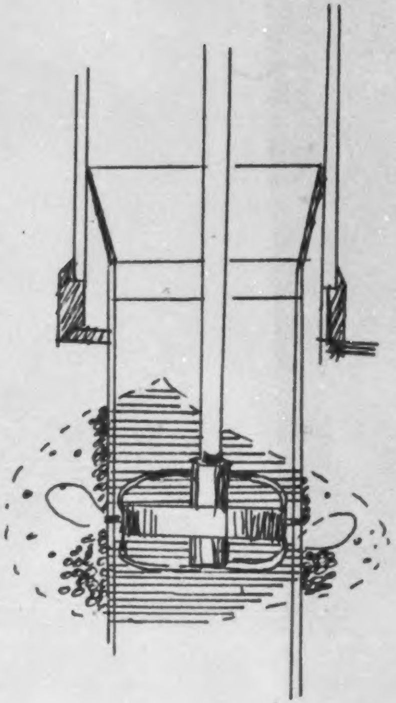
WELL DEVELOPMENT

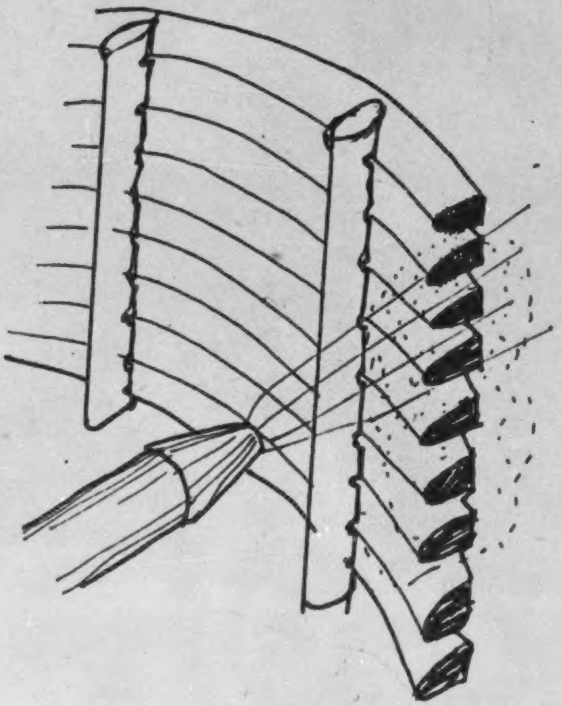
- Surging -



WELL DEVELOPMENT

- Jetting -



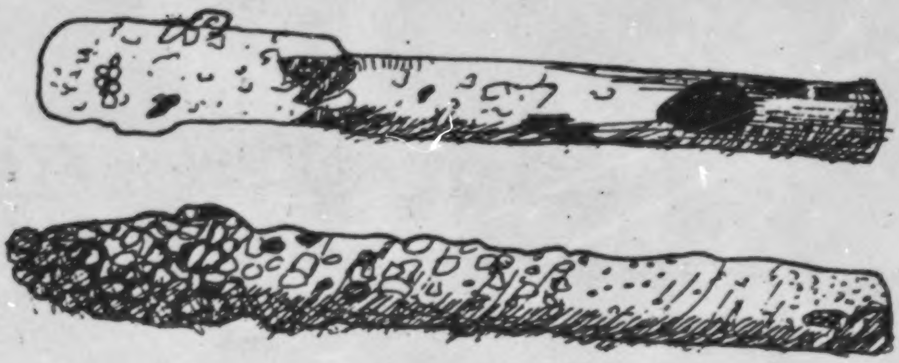


#16.

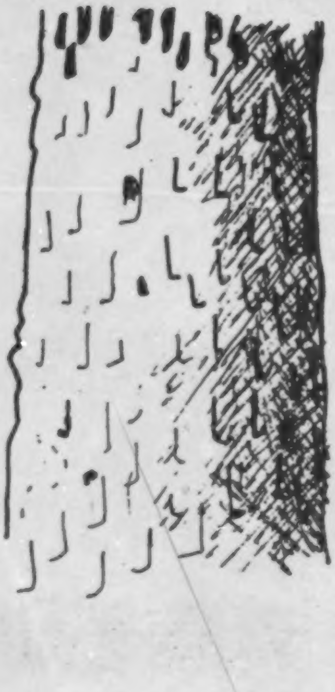
#17.

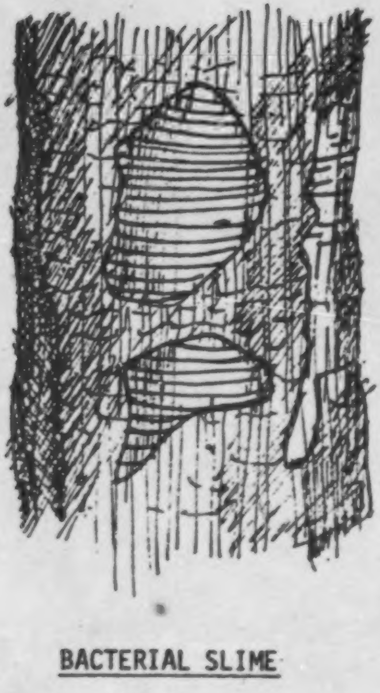
INCRUSTATION

DEPOSITION OF SOIL MATERIALS



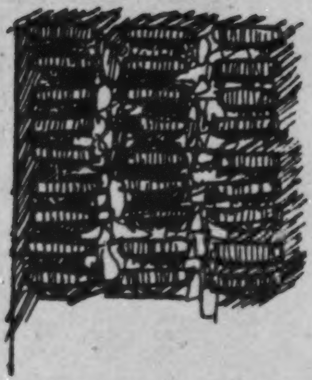
PRECIPITATION



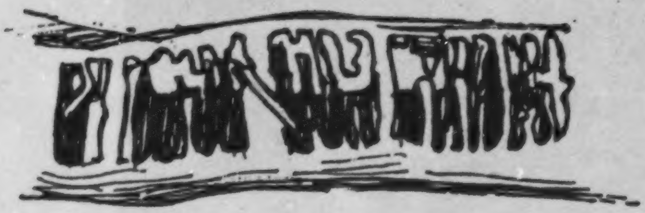


BACTERIAL SLIME

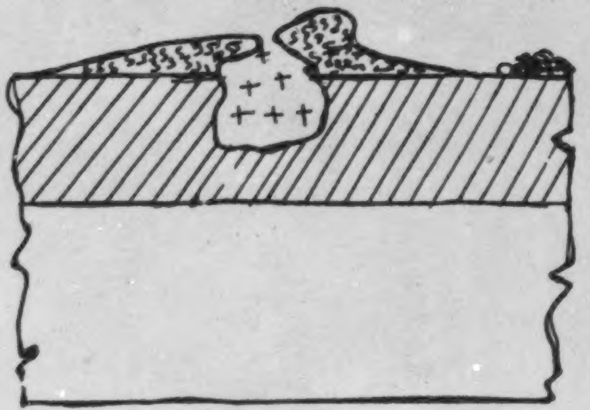
CORROSION



CORROSION YIELDING INCRUSTATION



TYPICAL CORROSION

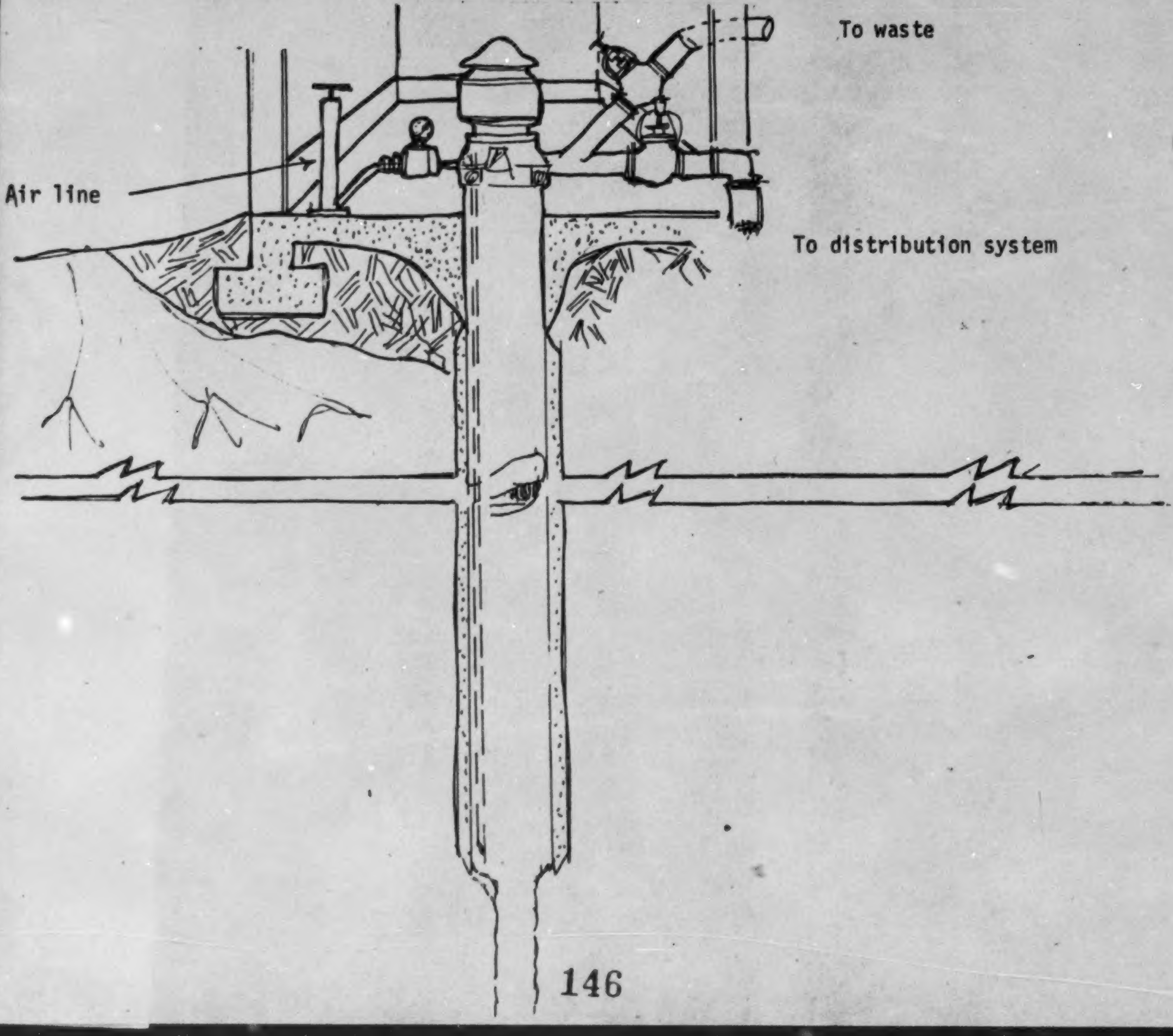


MECHANISM OF CORROSION LEADING TO INCRUSTATION

#18.

MEASURING DRAWDOWN

- Airline Method -


To waste
Air line
To distribution system

#20.

USE OF DRAWDOWN

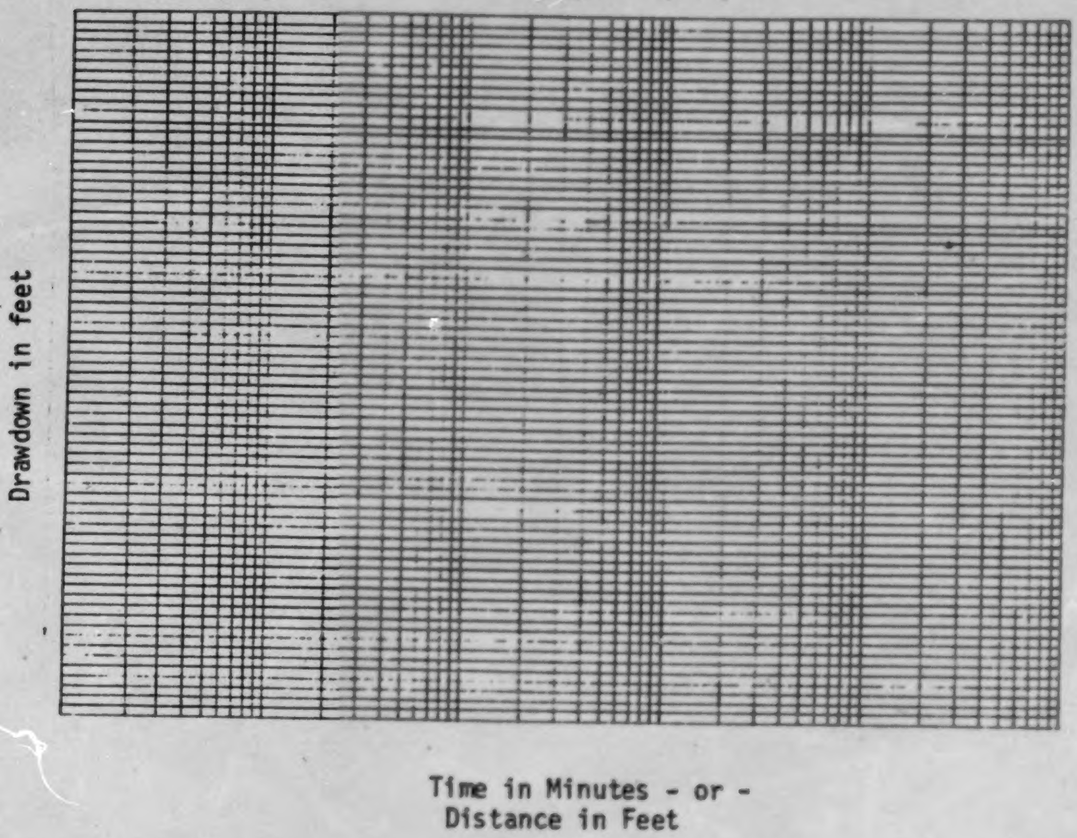
- Records and Problem Solving -

1. RECORD

   TIME SINCE PUMPING BEGAN VS. DRAWDOWN DISTANCE FROM WELL VS. DRAWDOWN

   TIME SINCE PUMPING ENDED VS. RECOVERY DRAWDOWN VS. YIELD.

2. GRAPH



3. COMPARE

   DRAWDOWNS

   YIELD

   RECOVERY

POROSITY

$\frac{V\ VOID}{V\ TOTAL}$ = % OF TOTAL THAT IS VOID SPACE

PERMEABILITY

K = EASE WITH WHICH FLUD CAN FLOW

TRANSMISSIBILITY

T = VOLUME OF FLOW/TIME/AREA

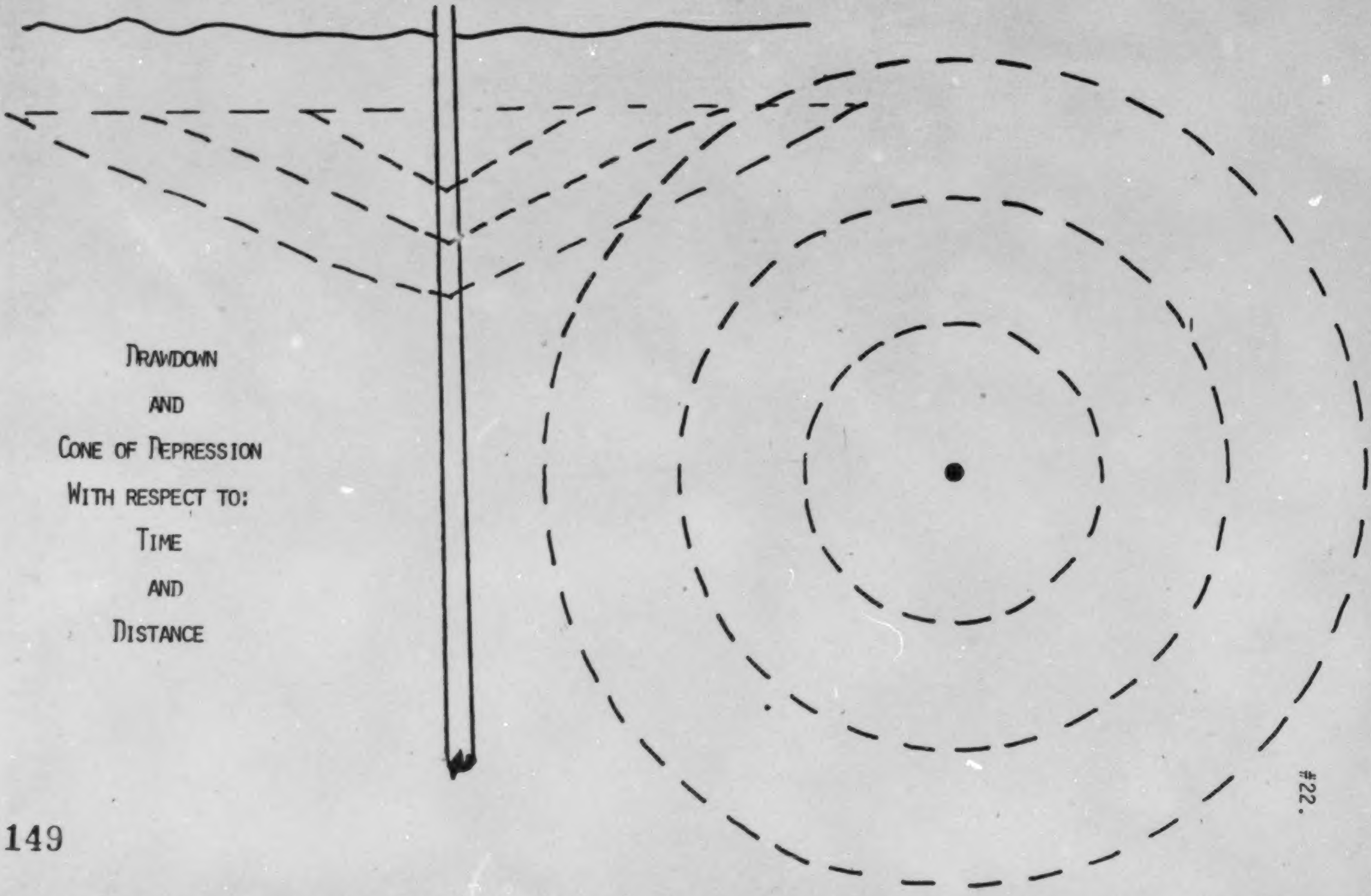
STORAGE COEFFICIENT

S = AMOUNT OF WATER RELEASED FROM STORAGE FROM A COLUMN OF AQUIFER WITH A UNIT UNDER A UNIT DECLINE IN HEAD

RULES OF THUMB:

A. CONFINED AQUIFER S = 0.1 TO 0.00001

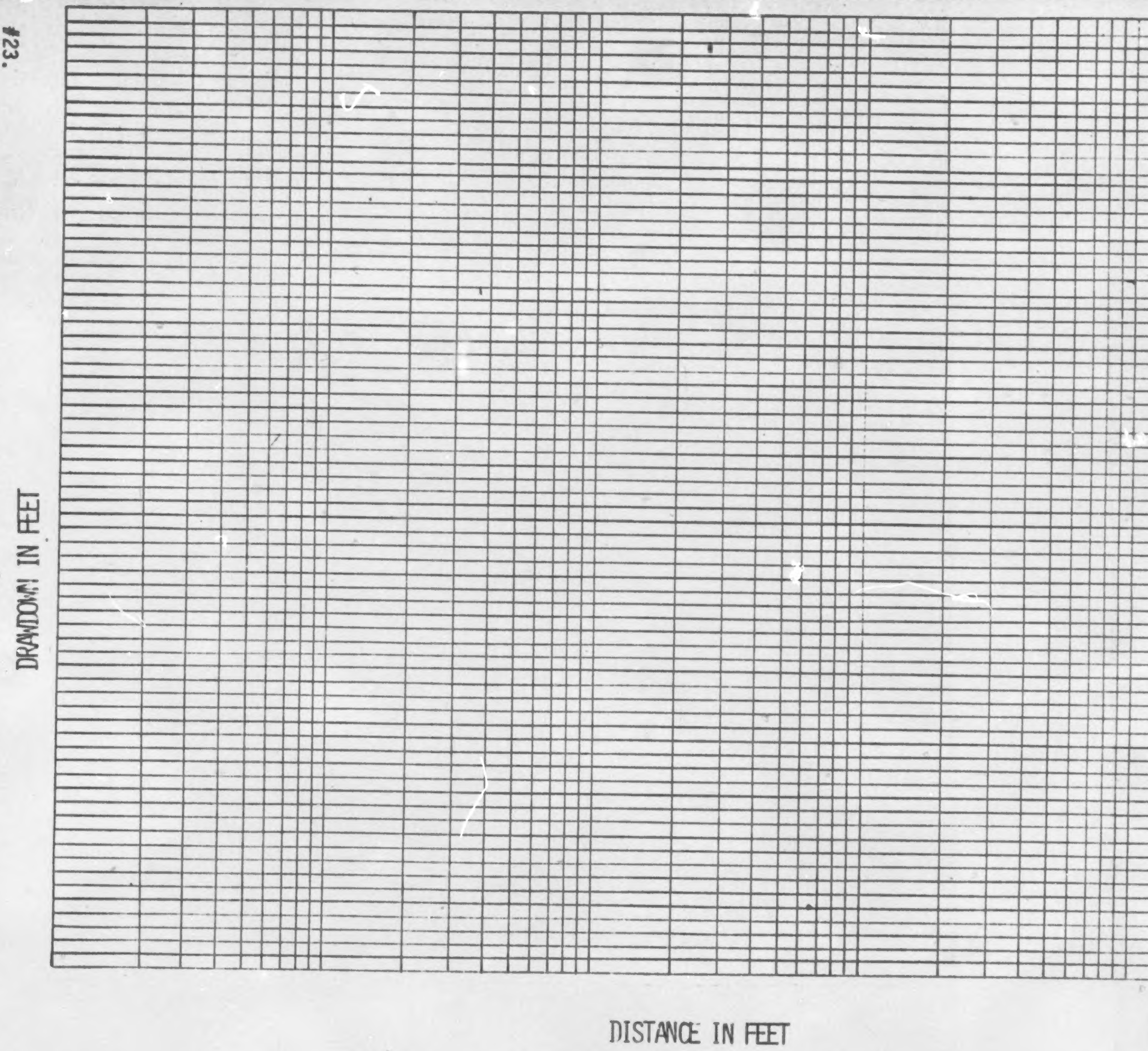
B. UNCONFINED AQUIFER S = 0.3 TO 0.1



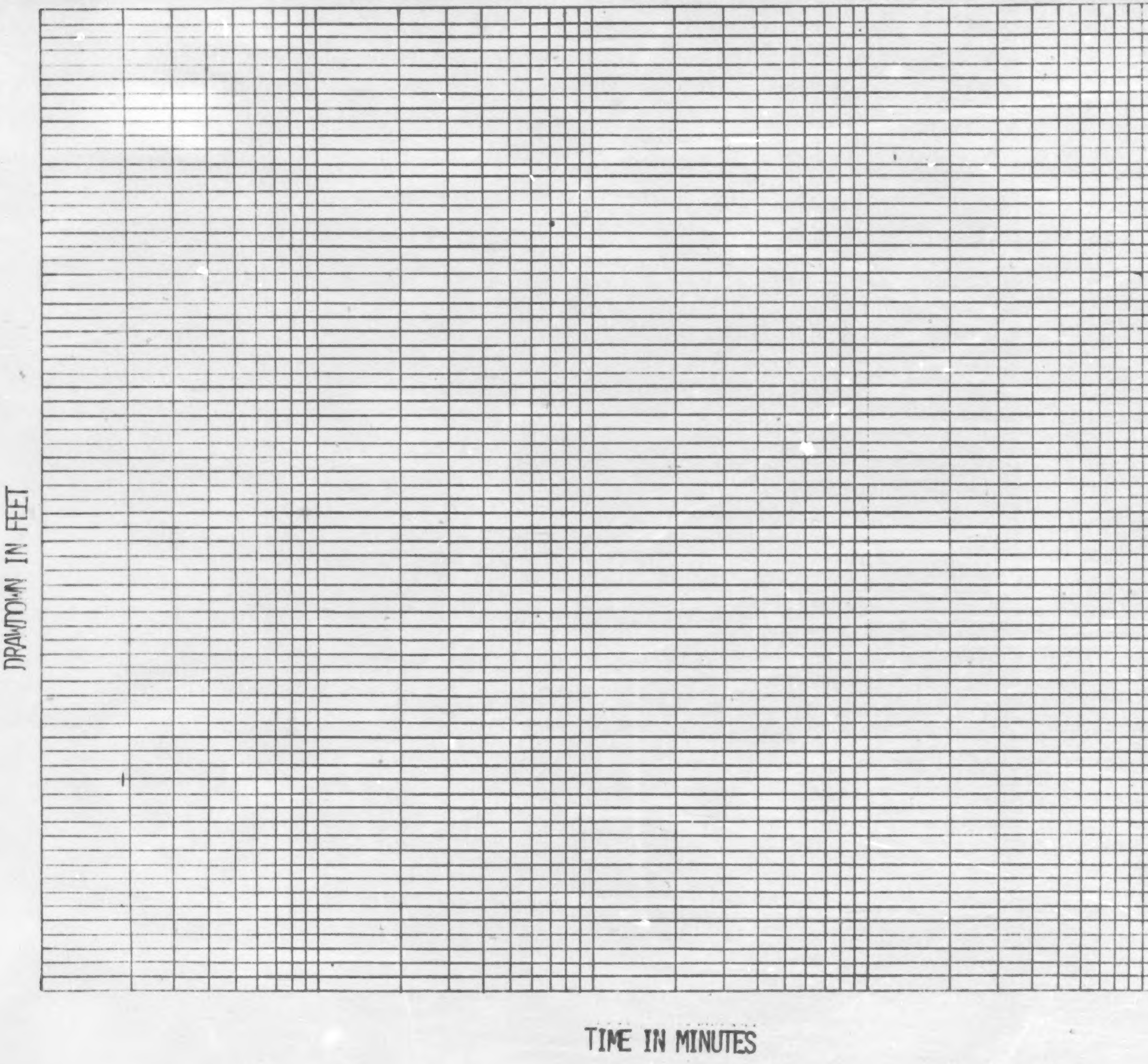
DRAWDOWN
AND
CONE OF DEPRESSION
WITH RESPECT TO:
TIME
AND
DISTANCE

#22.

#23.

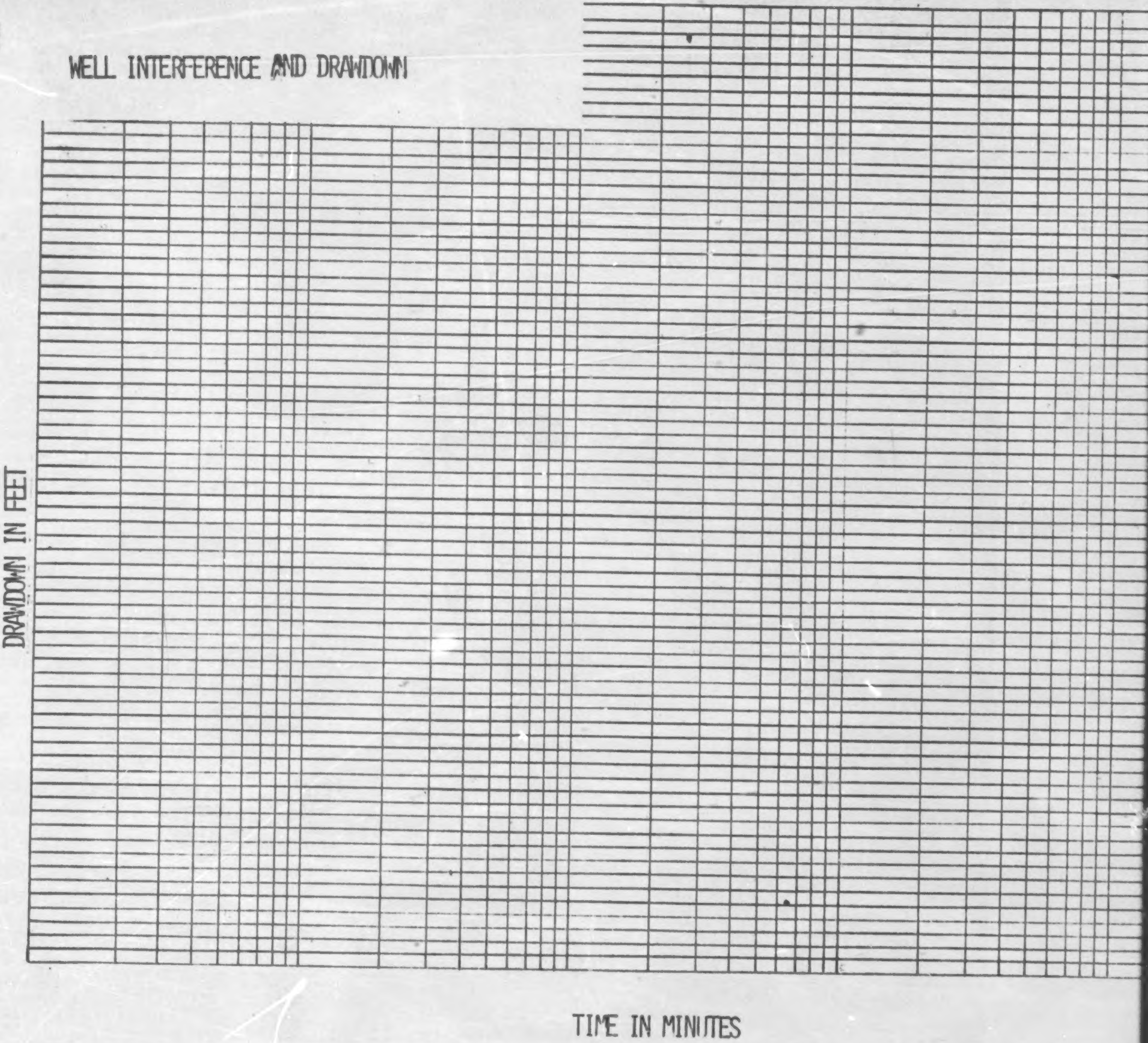


#24.



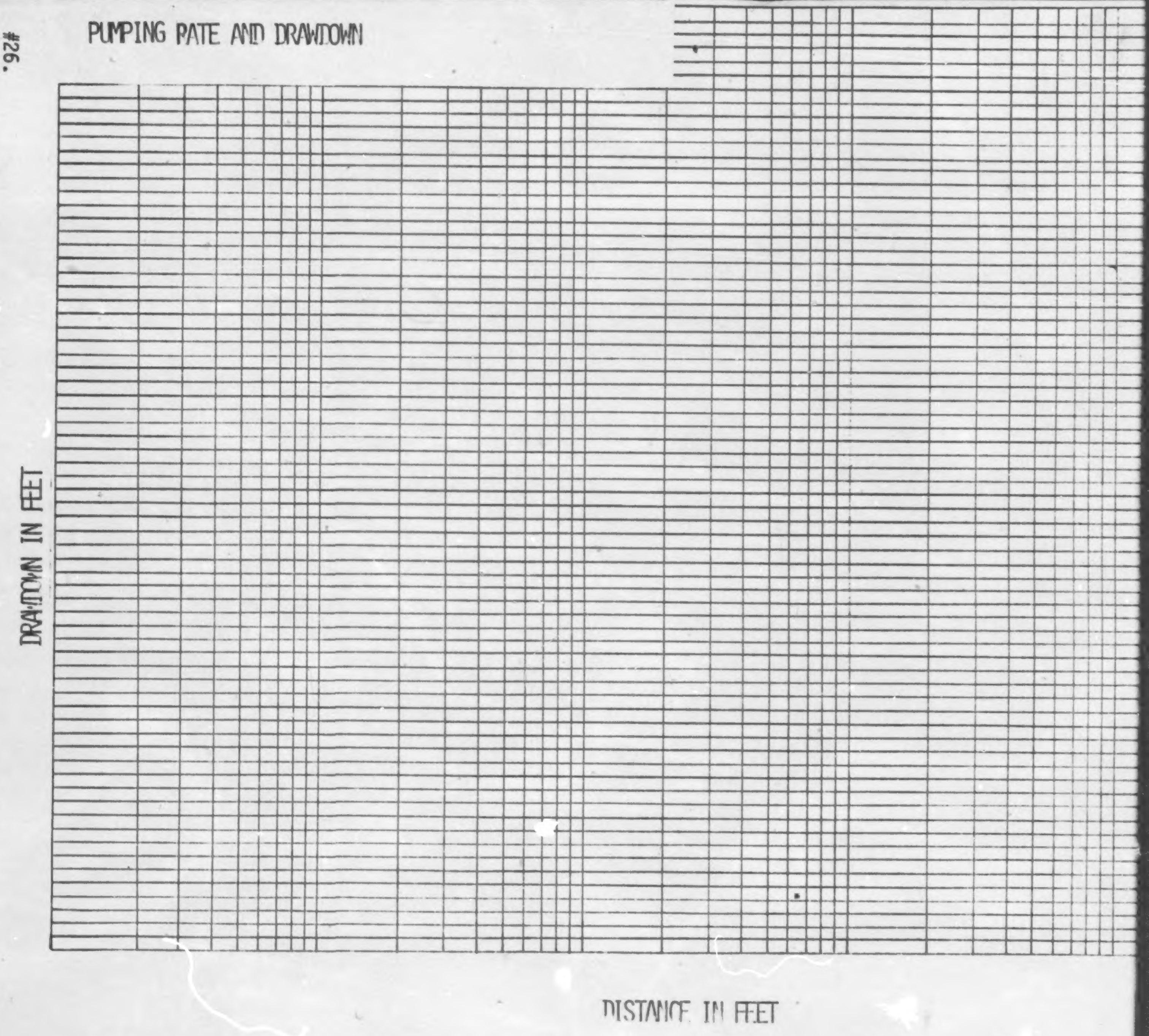
#25.

WELL INTERFERENCE AND DRAWDOWN



#26.

PUMPING RATE AND DRAWDOWN

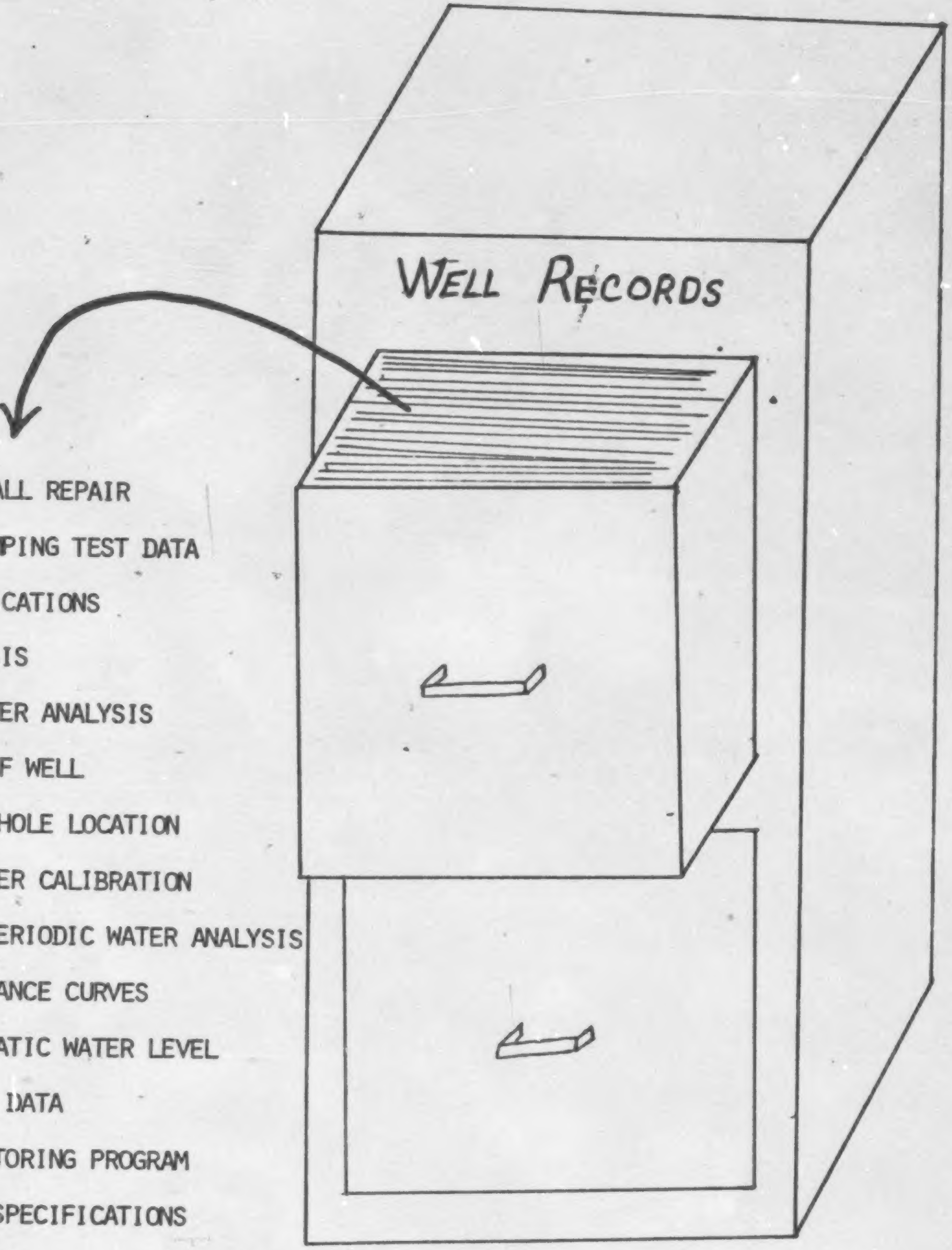


PROBLEMS?

1. CHART
2. COMPARE
3. CHECK RECORDS
4. THEORIZE SOLUTION
5. CONSULT EXPERTS
6. PLAN SOLUTION STEPS
7. PROCEED WITH SOLUTION

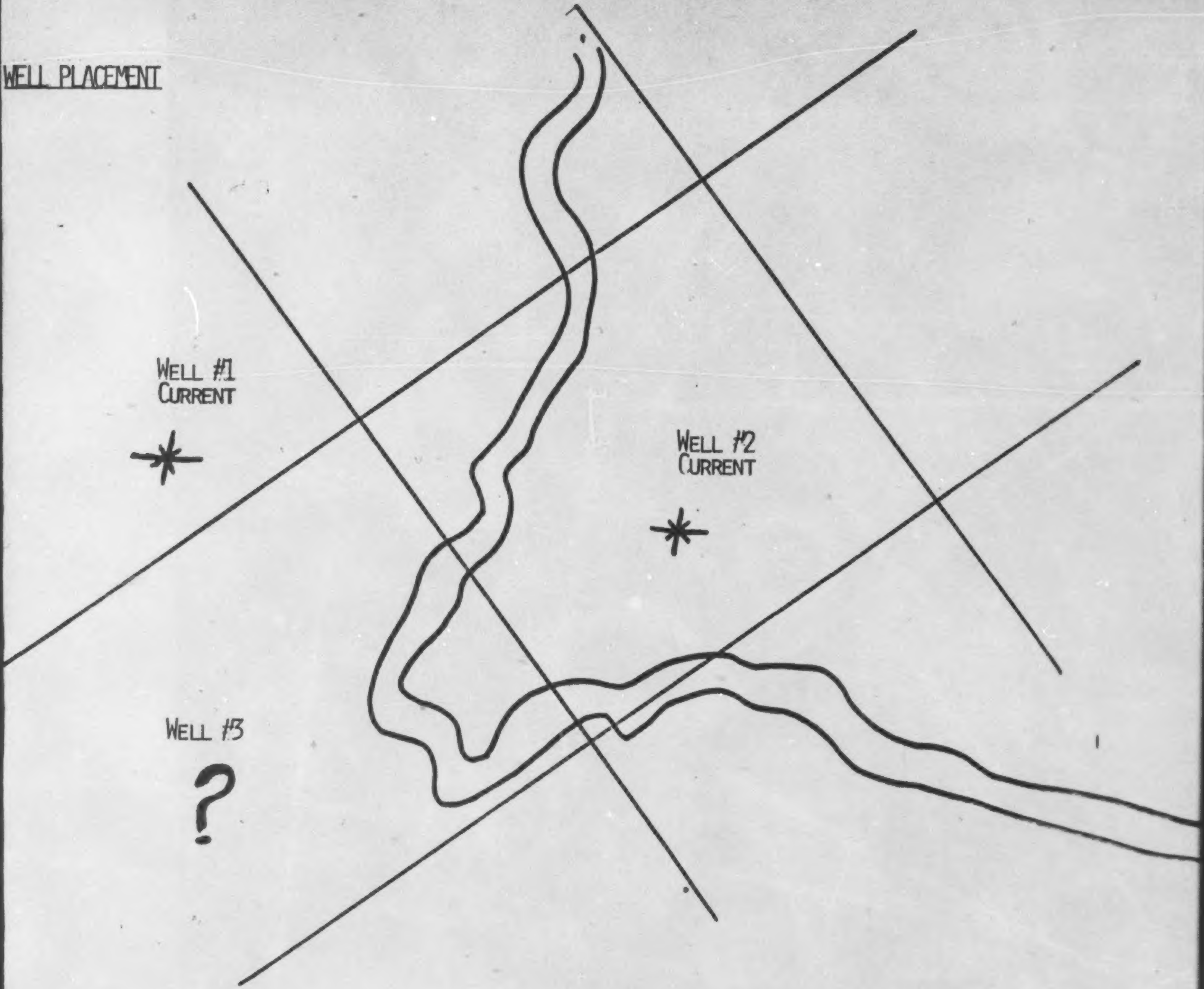
#27.

#28.

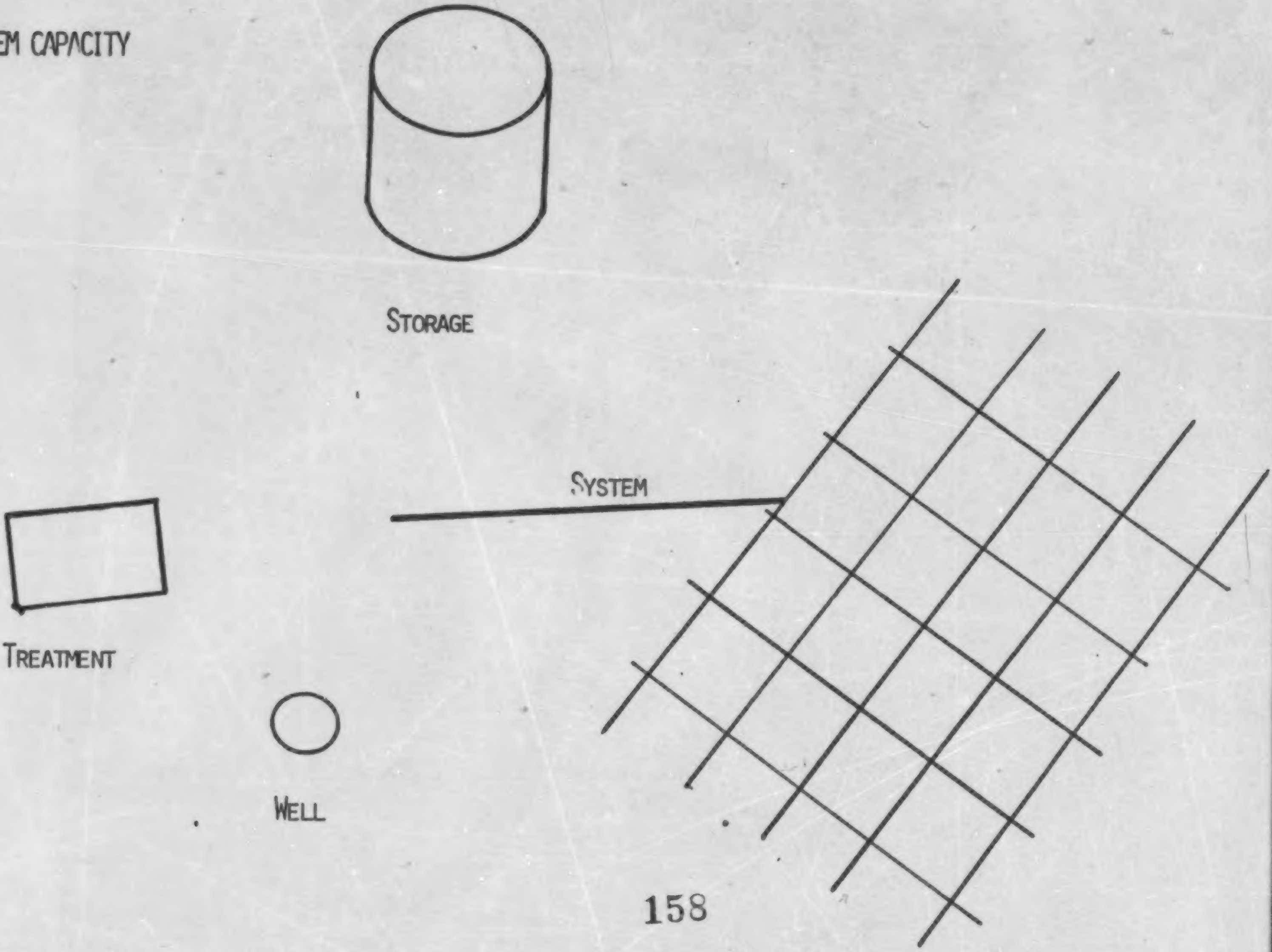


- DETAILS OF ALL REPAIR
- ORIGINAL PUMPING TEST DATA
- PUMP SPECIFICATIONS
- SIEVE ANALYSIS
- ORIGINAL WATER ANALYSIS
- BLUE PRINT OF WELL
- MAP OF TEST HOLE LOCATION
- DATES OF METER CALIBRATION
- RESULTS OF PERIODIC WATER ANALYSIS
- PUMP PERFORMANCE CURVES
- RECORD OF STATIC WATER LEVEL
- ALL GEOLOGIC DATA
- COPY OF MONITORING PROGRAM
- WELL SCREEN SPECIFICATIONS

WELL PLACEMENT


WELL #1
CURRENT
WELL #2
CURRENT
WELL #3
?

SYSTEM CAPACITY


STORAGE
SYSTEM
TREATMENT
WELL

Module No:	Module Title: Water Supply - Wells
	Submodule Title: Well Technology and Basic Maintenance
Approx. Time: 1 hour	EVALUATION Part A

Objectives:

Upon completion of this module, the participant should be able to correctly answer 75% of the evaluation questions.

Evaluation Questions:

1 - 12. Indicate whether the statement is true or false by marking T if true and F if false.

1.______ About 70% of the annual precipitation enters the ground water supply.

2.______ An aquifer with uniform large granuals has greater permeability than one with uniform small granuals.

3.______ The rate of flow through an aquifer is the specific yield.

4.______ A sanitary seal prevents the well from pumping sand.

5.______ All well screens are equally efficient.

6.______ Wells with submersible pumps require a well pit.

7.______ Well development is never necessary.

8.______ Well disinfection removes harmful chemicals from the water.

9.______ Incrustation is something the operator should not worry about.

10.______ The words corrosion and incrustation mean the same thing.

11.______ Maintenance is only necessary when a problem occurs.

12.______ Pump use means pump wear.

13 - 16. Diagram the following, labeling the parts indicated:

13. Diagram the hydrologic cycle

Label:
a. Transpiration
b. Precipitation
c. Runoff

14. Diagram an artisian aquifer

Label: a. Confining beds
b. Point of recharge
c. Static water level

15. Diagram a well

Label: a. Sanitary seal
b. Well casing
c. Well screen

16. Diagram a water table aquifer

Label: a. Confining bed
b. Water bearing formation
c. Percolation

17 - 25. Choose the best answer:

17. A water shed is

a. A building for storing water
b. The same as a river
c. The area drained by a particular river
d. A type of well

18. Movement of ground water through clay is

a. Rapid
b. Slow
c. Variable

19. The void space between the sand grains in an aquifer is defined as

a. Porosity
b. Permeability
c. Transmissibility
d. Specific yield

20. An artificial gravel pack is necessary

a. In a consolidated rock well
b. When natural gravel is very fine
c. In all wells
d. Both a and b

21. A basic difference between the rotary and cabel tool drilling methods is

    a. How and when the casing and screen are set into place.
    b. What type of pump is put in
    c. A rotary drilled well needs no development
    d. All of the above

22. The purpose of developing a well is to

    a. Sanitize the well
    b. Increase the well yield
    c. Repair a corroded well screen
    d. Grind down rough edges on a pump

23. Incrustation can be caused by

    a. Iron bacteria
    b. Manganese
    c. Magnesium
    d. Iron
    e. All of the above

24. Jetting is

    a. A method of disinfecting a well
    b. A method of cleaning a well
    c. Another name for a clogged screen
    d. A method for determining draw down

25. An air line in the well is used to measure

    a. Flow
    b. Water level
    c. Corrosion
    d. Water pressure

26 - 33. Answer the following questions in 1 sentence or less.

26. When is a well screen not necessary?

27. Why is a sanitary seal required on all wells?

28. Why can't the auger be used to drill below the water table?

29. What type of acid is usually used when treating an incrustation problem?

30. Chlorine treatment is used for what two things when treating well problems.

31. Is fractured limestone a consolidated or unconsolidated aquifer formation.

32. Why must routine maintenance be established?

33. Why must routine maintenance procedures and test results be recorded in a permanent file?

Module No:

EVALUATION Part A

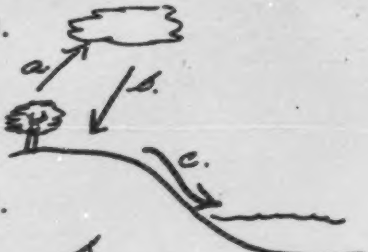
Instructor Notes:

Evaluation Handout A

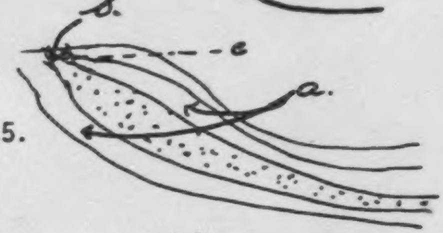
Answers:

1. False
2. True
3. False
4. False
5. False
6. False
7. False
8. False
9. False
10. False
11. False
12. True

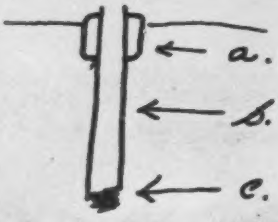
13.



14.



15.



Instructor Outline:

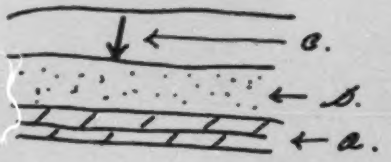
Give the participant Part A of the Water Supply - Wells Evaluation after completing the submodule over Well Technology and Basic Maintenance.

Module No:	EVALUATION

Instructor Notes:

Instructor Outline:

16.



17. c

18. b

19. a

20. b

21. a

22. b

23. e

24. b

25. b

26. In a consolidated rock aquifer

27. It protects the well and aquifer from surface contamination

28. The auger flight will no longer carry material upward

29. Usually muramic (sometimes sulfamic)

30. Cleaning bacterial slime from well screen and disinfecting the well

31. A consolidated rock aquifer formation.

32. It corrects minor well problems before they become major

33. It must be used for comparisons when analyzing data to predict pending well problems

Module No:	Module Title: Water Supply - Wells
	Submodule Title: Evaluation of Well Performance
Approx. Time: 1 hour	EVALUATION - Part B

Objectives:

Upon completion of this module, the participant should be able to correctly answer 75% of the evaluation questions.

Evaluation Questions

1 - 7 Indicate whether the statement is true or false by marking T if true and F if false.

1._____Permeability decreases as partial size decreases.

2._____Drawdown curves become straight lines when plotted on semi log paper.

3._____Doubling the well diameter will double the yield per foot of drawdown.

4._____Increasing the pumping rate will increase drawdown.

5._____Problems with the well can sometimes be predicted by analyzing past and present pumping test data.

6._____The permanent record file should be accessible to anyone in the city.

7._____A water tower can be placed anywhere on the system with the same effect on the system.

8. Which of the following things must be included in the permanent record file of the well.

   a. Details of all repair
   b. Original pumping test data
   c. Pump specifications
   d. Sieve analysis
   e. Original water analysis
   f. Blue print of well
   g. Map of test hole location
   h. Dates of meter calibration
   i. Results of periodic water analysis
   j. Pump performance curves
   k. Record of static water level
   l. All geologic data
   m. Copy of monitoring program
   n. Well screen specifications

9. Given:

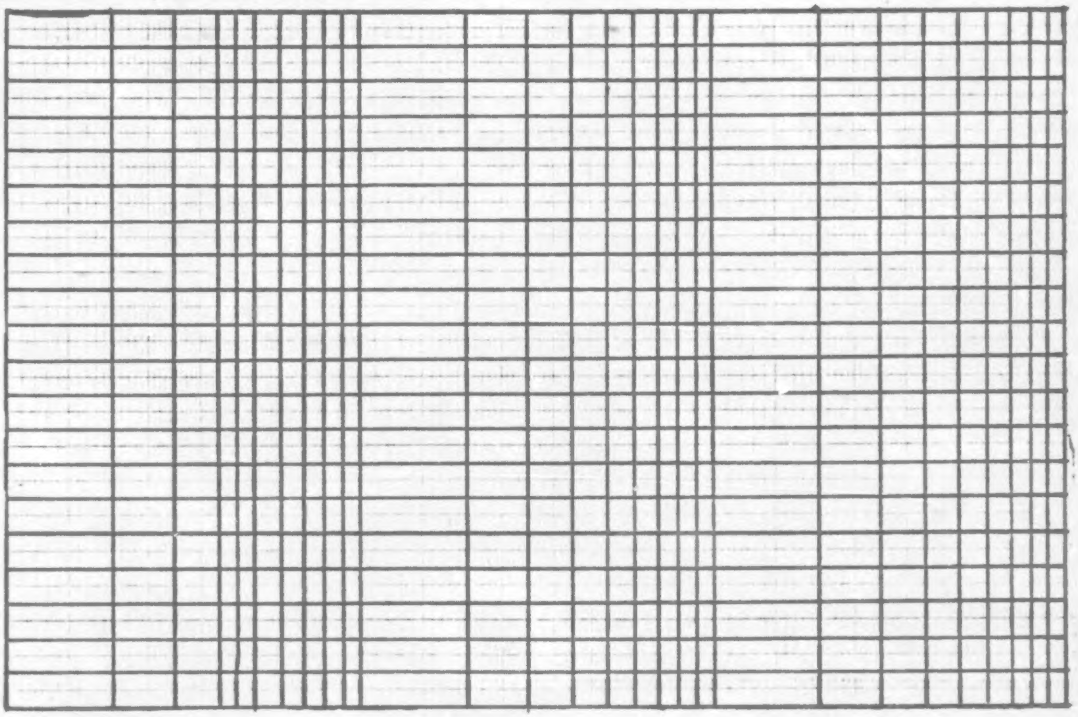
For observation Well A:

10 min. of pumping drawdown = 4'

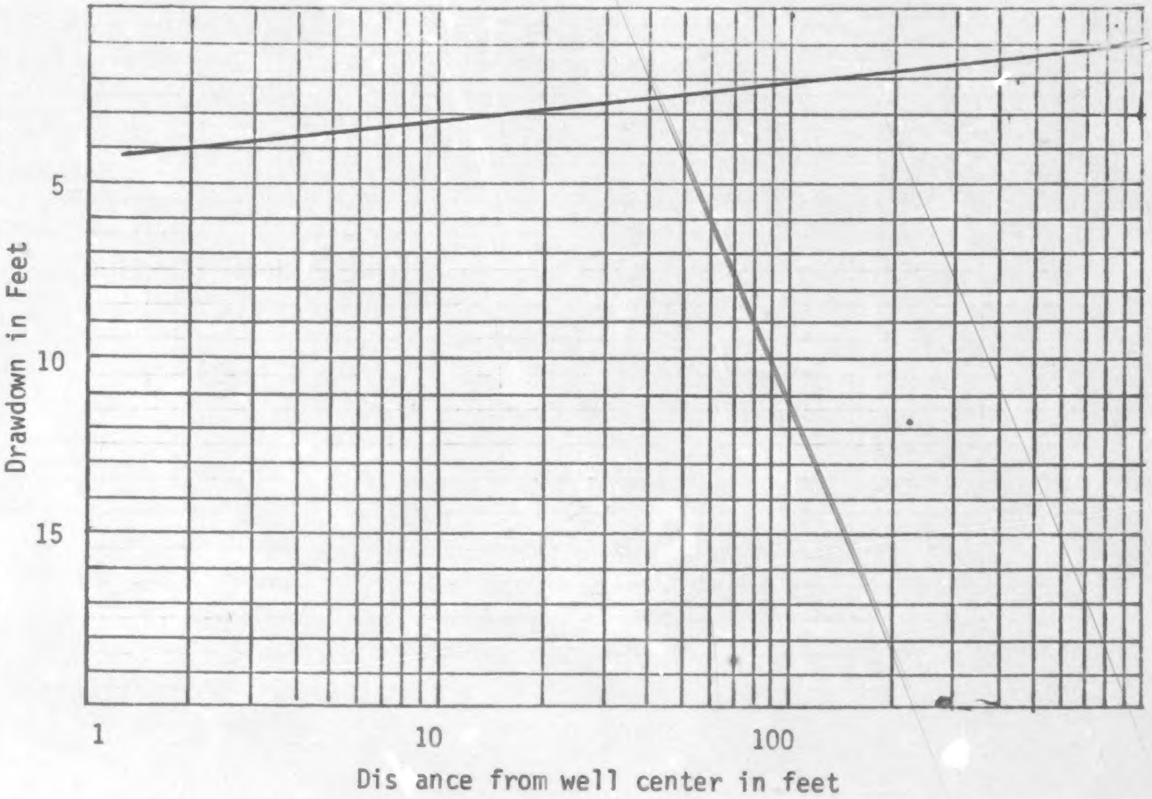
100 min. of pumping drawdown = 8½'

500 min. of pumping drawdown = 11½'

Plot time drawdown on semi log paper



Given the following information



Pumping Rate = 500 gpm

Time = 100 Min.

T = 26,400 gpd/ft.

S = 0. 0097

10. Does this well most likely penetrate an artisian or water table aquifer?

11. At what distance from the center of the pumped well is there 1 foot of drawdown after 100 minutes pumping time?

12 - 14 Given these two sets of data from a single well

1976 data		1977 data
100'	Static water level	99'
25'	Drawdown (in well) at 100 Min.	40'
500 gpm	Yield of well	200 gpm
.04	Storage coefficient	.000001

12. Where the problem most probably lie?

_____A. The pump

_____B. The well screen incrusting

_____C. The aquifer depleting

_____D. There is no problem evident

13. What can be done to correct it?

_____A. Nothing

_____B. Replace pump

_____C. Chlorine treatment

_____D. Acid treatment

14. What additional records would you remove from the permanent record file?

_____A. Screen warranty and specifications

_____B. Pump warranty and specifications

_____C. None

_____D. Sieve analysis

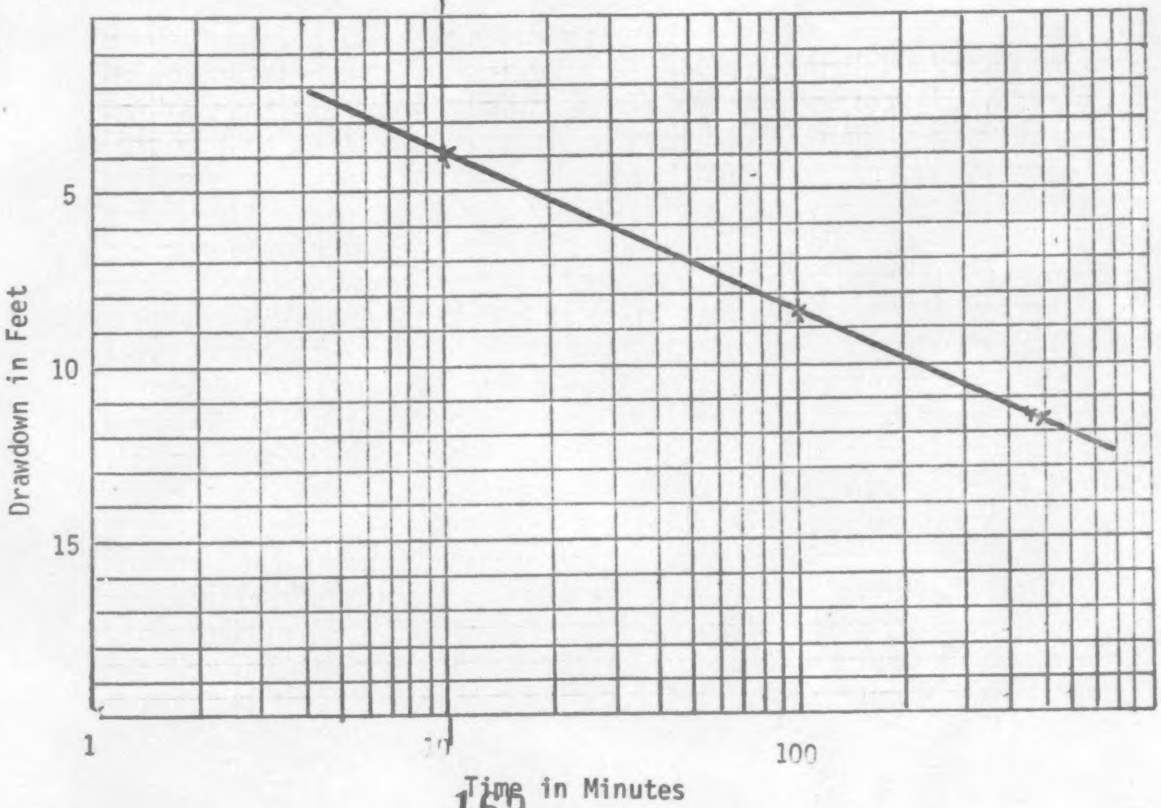
Module No:	Topic: EVALUATION - Part B

Instructor Notes:	Instructor Outline:

Evaluation Handout B

Answers:

1. True
2. True
3. False
4. True
5. True
6. False
7. False
8. All answers a - n are correct and should be circled.
9.



Give the participant Part B of the Water Supply - Wells Evaluation after completing the submodule over Evaluation of Well Performance.

Module No:	Topic: EVALUATION

Instructor Notes:	Instructor Outline:
10. Artisian aquifer 11. 800 ft. to 900 ft. 12. B 13. d 14. A	

Module No:	Module Title: Water Supply - Wells
	Submodule Title:
Approx. Time: 1 hour	EVALUATION - Part C

Objectives:

Upon completion of this module, the participant should be able to correctly answer 75% of the evaluation questions.

Evaluation Questions

1 - 9 Choose the best answer.

1. Well interference is created by

_____A. The cones of depression overlapping

_____B. A river too close to the wells

_____C. Overpumping an aquifer

2. When pumping rate increases drawdown

_____A. Increases

_____B. Decreases

_____C. Remains unchanged

3. Rate of recharge ideally equals

_____A. One foot per minute

_____B. Rate of drawdown

_____C. Two times rate of drawdown

4. How can well efficiency affect the cost of pumping?

_____A. Well efficiency doesnot affect cost of pumping.

_____B. The more efficient the well is, the less extensive the water treatment needs to be.

_____C. As efficiency decreases, drawdown increases.

5. A performance contract

_____A. Specifies only details of design and construction

_____B. Specifies only the desired final result

_____C. Specifies what the driller is to do and how it is to be done

6. A comprehensive-specification contract

_____A. Specifies only details of well design

_____B. Specifies only the desired final result

_____C. Specifies what the driller is to do and how it is to be done

7. The choice of a contract depends on a variety of factors including:

_____A. Completeness of background data

_____B. Competencies of owner and contractor

_____C. Both A and B

8. In order to keep bids as low as possible

_____A. Use the smallest diameter hole that is practical

_____B. Split screen sections into very short segments

_____C. Both A and B

9. The contractor should be required to

_____A. Guarantee well yield

_____B. Provide performance warranties on components of the well

_____C. Guarantee quality of water produced

10 - 12 Answer in one sentence or less.

10. How can old well records be of help when placing a new well which will penetrate the same aquifer.

11. What are two major functions of a water tower.

12. Which major factor must be used in computing the adequacy of the capacity of a system.

Module No:	Topic: EVALUATION - Part C

Instructor Notes:	Instructor Outline:
Evaluation Handout - Part C Answers: 1. A 2. A 3. B 4. C 5. B 6. C 7. C 8. A 9. B 10. These records will show the extent of the cone of depression. 11. Maintain constant pressure and provide a reservoir of water which is immediately available for use. 12. Water requirements for adequate fire protection.	Give the participant Part C of the Water Supply-Wells Evaluation after completing the submodule over Basic Well Management.